Technical, economic and energetic competitiveness of rail-road combined transport: evaluation of the effects of possible ITS applications on intermodal terminal.

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Technical, economic and energetic competitiveness of rail-road combined transport

Evaluation of the effects of possible ITS applications on intermodal terminal

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Angela Carboni

Turin, April 11, 2019

Summary

Road transport has been the most used mode for freight transport in many European countries for several decades. In this century, due to the growing awareness of sustainability problems in this field, the European regulations provide much guidance to meet requirements of environmental sustainability. The intermodal transport could be a good solution to achieve these requirements and can be an eco-friendly option for medium/long distance connections thanks to the use of railway for the longer part of the path. The research activities focused on two main elements: the rail-road combined transport (chain level) and the intermodal terminal (node level). These aspects are strictly correlated due to the important role of the intermodal terminal in the competitiveness of rail-road combined transport. On the other hand, the study of the entire transport process is fundamental to define the terminal requirements and performance.

The typical rail-road combined transport process is described by standard language (*Systems Modelling Language*) to represent the complex relations between the actors involved in the process and their main activities.

After examining the process, the range of competitiveness of rail-road combined transport in terms of covered distance is analysed. The analytic approach considers the different phases of transport chain and investigates parameters such as the external costs and the location of terminals. The function obtained for rail-road combined transport costs is obviously discontinuous due to the presence of terminals and their costs items which are independent on covered distance. The main results obtained show that the rail-road transport may be competitive if the external costs are internalised and if the total distances are enough to exploit the advantages of rail transport. The cost for terminal operations can limit the competitiveness of combined transport solution, confirming its essential role. These considerations may not be suitable in some cases, such as in case of a short distance (seaport and dry port connection) covered by a shuttle train: scheduled and fixed

composition, large quantities of goods with the same path. This type of service allows lower costs for terminal operations and the elimination of initial part covered by road. To better analyse the freight door-to-door movement, the thesis includes a focus on section of transport chain: the last mile covered by road and the role of GPS positions on accessibility measure. The method proposed has the potential to solve the issue of hubs locations, to better evaluate the compatibility between electric vehicles and urban trips and to evaluate the role of ITS (AVL - Automatic Vehicle Location, for instance).

In the second part of this thesis, the typical internal process for intermodal terminal is investigated and represented through standard language. After that some performance indicators for each phase of terminal process obtained through an extensive literature review are collected and classified with traceability matrices correlating them to actors involved and the scope. Later, the focus was on the manual or automatic terminal gate operations. The manual identification of transport units and vehicles may cause a chance of errors while automatic identification sensors can avoid them improving, among other things, this part of terminal process. Two main classes of sensors are considered: one based on optical identification and other on the radiofrequency. To sum up, the technologies can contribute to terminal performance improvement or can help the computation of the indicators itself.

One of the goals of this thesis is to propose and evaluate, through simulation and analytical approach, the effects of possible ITS (*Intelligent Transport Systems*) applications on intermodal terminals, in terms of throughput and energy efficiency. The first method is the standard system architectures representation to support the calculation of indicators. The architectures allow a clear communication with stakeholders and show at which points of the process the indicator can be measured also in different scenarios. The second approach is the terminal simulation to evaluate the quality and energy performance of inland freight terminals, using a quantitative approach based on traffic microsimulation models. The model allows a comparison of chosen performance indicators in several scenarios using realistic data. The main results show that the fuel consumption is consistent with the level of congestion inside the terminal and the use of technologies could improve the performance of intermodal terminal also in the case of worst scenario. Finally, the third approach is the application in the field. The monitoring phase aims to elaborate the data from the use of video technologies in the first phase and after of Bluetooth and Wi-Fi sensors. After investigating different monitoring scenario, the final trends obtained from data collected with BT sensors are relatively similar to the typical traffic flow inside the terminal.

Acknowledgment

I wish to thank the partners of the Project Cluster ITS Italy 2020 - Ministero dell'Istruzione, Università e Ricerca (MIUR) (Italian Ministry of Education, University, and Research) for the appreciated suggestions given during the development of the study.

The case study and methodology studied in section 2.3 are partially developed in the SUITS -Supporting Urban Integrated Transport Systems: Transferable tools for authorities (http://www.suits-project.eu/) project, which has received funding from the European Union's Horizon 2020 Framework programme for research and innovation under grant agreement no 690650.

I would like to dedicate this PhD thesis to my loving husband

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Chapter 1

Introduction

Freight transport is a vital component of the economy and development of regions, but its dramatic growth in the road sector is rapidly offsetting the benefits through such impacts as congestion, noise, pollution and environmental damage. Alternatives such as a combined transport network can help to reduce these impacts (Martínez, Gutiérrez, Oliveira, & Bedia, 2004). To make transportation more efficient in the entire logistic chain, different modes of transport are used, depending on availability, capacity and costs (European Union Agency for Railways, 2018).

The transport market is moving toward intermodal transport since the combination of several modes into an integrated continuous system can provide a more flexible, reliable, profitable, and sustainable service with respect to classical unimodal transport (Dotoli, Epicoco, Falagario, Seatzu, & Turchiano, 2017). In fact, intermodal solution consists in taking advantage of the operational benefits (as cost, capacity, flexibility and environmental sustainability) of transport modes, then merging them into a single transport chain. Although for transporting cargo over long distances, as rail and waterway transport are more efficient, there are additional cost and obstacles in transhipment with other modes.

In this thesis, starting from the regulation framework which underlined the current political inputs for more sustainable transport solutions, the intermodal transport solution is evaluated in second chapter. The analysis starts from the rail-road freight transport chain process description, with the focus on the last mile cover by road, and then focuses on the technical-economic competitiveness as an alternative to the road choice. The economic analysis, through an analytical approach, includes both internal and external costs. The technical part regards mainly the mode features and environmental consideration, also considering some possible exceptions as alternative fuels for pre and post-haulage or the rail transport over short distances with specific characteristics (dry port and seaport connections).

One of the outputs of the second chapter is the important role of intermodal terminal in rail-road combined transport competitiveness. In fact, the rail-road terminal and its process are the focus of the third chapter together with an overview on performance indicators and automatic identification sensors related to this context. Finally, the attention is on the influence of possible ITS solutions on the terminal process using three main approaches: the system architecture representations using standard language, the microsimulation and the field-monitoring. The conceptual map of this thesis is reported in Fig. 1 to sum up the steps to achieve the goals underlining the relations between the chapters and paragraphs.

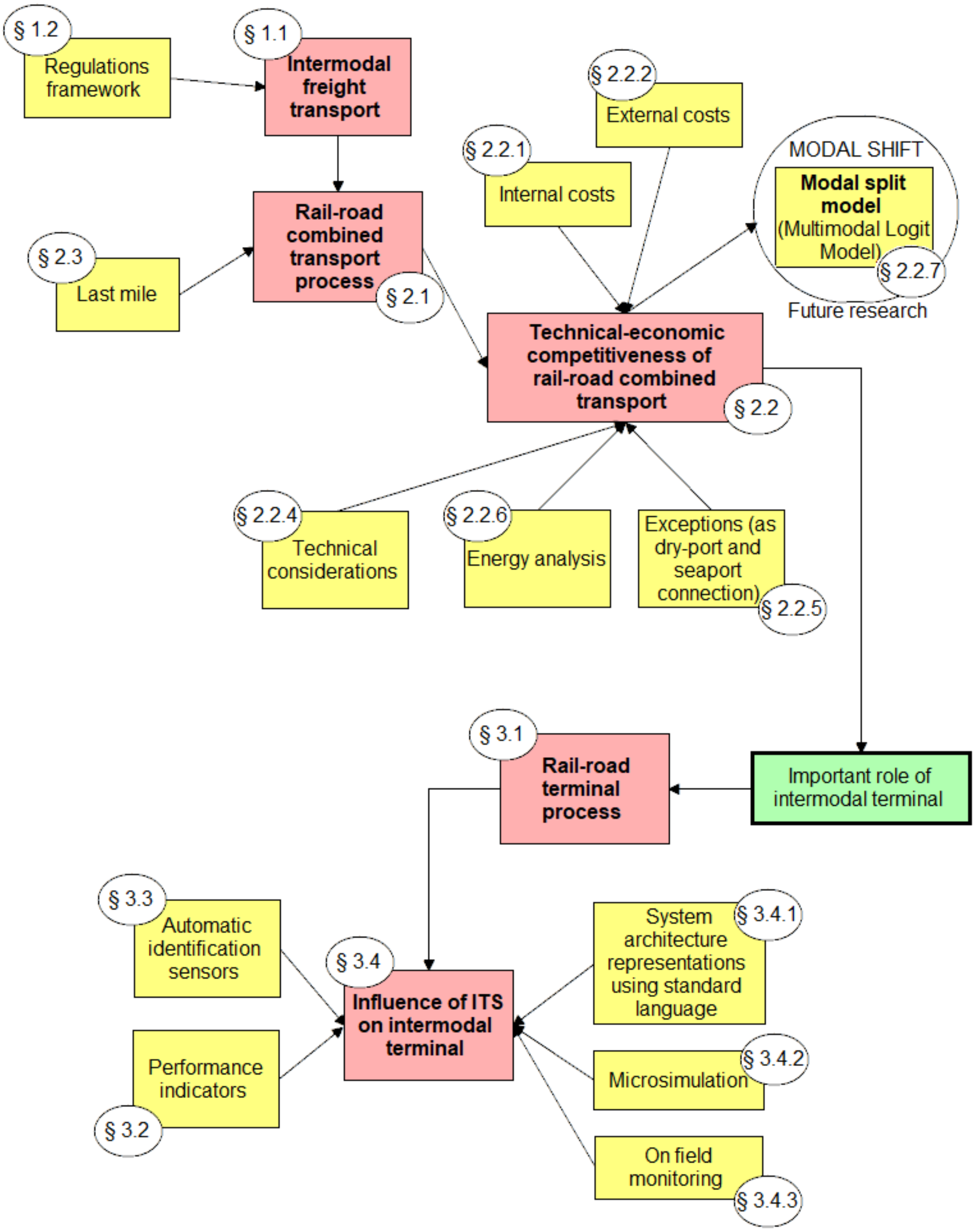


Fig. 1 Conceptual map with the main topics and methods of this PhD thesis

1.1 Intermodal freight transport

The intermodal transport is defined as a transhipment of goods through the same transport unit using two or more transport means and without the manipulation of the freight themselves (UNI/CE). A modal shift is carried out by using suitable handling equipment in specific nodes of the transport network, i.e. *inland terminals* (sometimes called freight stations, that is, when depot areas are included), which may or may not be matched with a freight village or a logistics center (Dalla Chiara, 2015).

The Directive 92/106/EEC defines the "combined transport" as "the transport of goods between Member States where the lorry, trailer, semi-trailer, with or without tractor unit, swap body or container of 20 feet or more uses the road on the initial or final leg of the journey and, on the other leg, rail or inland waterway or maritime services". The following conditions have conventionally been considered in the last few decades for funding reasons, although they now seem to have been exceeded:

a) the path covered by railway, sea or inland waterways should exceed 100 km, as the crow flies;

b) the initial or final parts of the road journey should include the path between the freight loading point and the nearest suitable loading railway terminal, or the freight unloading point and the nearest suitable unloading railway terminal, otherwise Should be included within a radius that does not exceed 150 km, as the crow flies, from the loading or unloading inland waterway port or seaport.

According to the proposal for a new Directive of the European Parliament and of the Council amending Directive 92/106/EEC on the establishment of common rules for certain types of combined transport of goods between Member States, the definition of Combined Transport is: "carriage of goods by a transport operation, consisting of an initial or final road leg of the journey, or both, as well as a non-road leg of the journey using rail, inland waterway or maritime transport:

(a) in a trailer or semi-trailer, with or without a tractor unit, swap body or container, identified in accordance with the identification regime established pursuant to international standards ISO6346 and EN13044, where the load unit is transhipped between the different modes of transport; or

(b) by a road vehicle that is carried by rail, inland waterways or maritime transport for the non-road leg of the journey.

Non-road legs using inland waterway or maritime transport for which there is no equivalent road transport alternative, or which are unavoidable in a commercially viable transport operation, shall not be taken into consideration for the purposes of the combined transport operations."

The transport by railway, sea or inland waterways is preferred on long distances for economic scale reasons to reduce the impact of road transport, whereas the initial and final haulage are managed in road transport mode, because it provides more flexibility and accessibility (Carreira, Santos, & Limbourg, 2012). Although for long distances, rail and waterway transport are more efficient, there are additional cost and obstacles in transhipment with other modes, so the role of terminals is relevant. Take advantage of the operational benefits (as cost, capacity, flexibility and environmental sustainability) of transport modes, then merging them into a single transport chain is the crucial point of intermodal solution. Furthermore, to be sustainable the intermodal transport must be efficient for all the actors involved in the process.

In Europe in 2016 the 72% of CO_2 transport emissions is due to road transportation in comparison with the 0,5% of rail sector; in particular CO_2 emissions from heavy goods vehicles represent around 30% of all road transport emissions (European Commission, 2018). Reducing the number of lorries on the road will mean a reduction of emissions and air pollution by the freight transport sector, as well as reduced congestion and accidents on our roads (European Union Agency for Railways, 2018). Fig. 2 shows that, in the European Union countries, only in Latvia and Lithuania the road transport mode has a contained share in refer to total percentage of freight transport, whereas in the other countries it still largely, probably due to different geographical contexts or policies adopted.

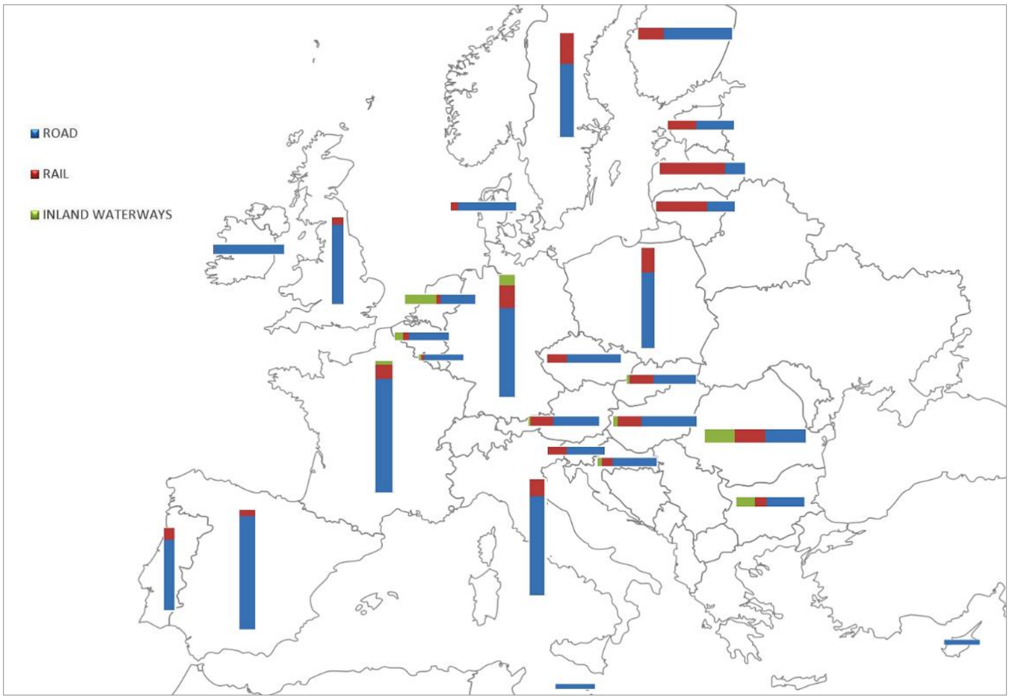


Fig. 2 Inland freight transport modal share [original data from (European Commission, 2018)**]**

In this thesis, the author will mainly deal with rail-road combined transport or *ferroutage*, where the main distance is covered by rail, and the road solution is only adopted for pre- and post-haulage. Where not otherwise specified the term "combined transport" refer to a specific type: unaccompanied transport, in which the driver therefore does not follow the goods along the path covered by the alternative mode. In 2017, the unaccompanied combined transport segment's market share amounts to approx. 95% of the total combined transport market (BSL Transportation Consultants & UIC Intermodal Union of Railways, 2019).

The freight traffic share which choses combined transport solution has grown 68% from 2000 to 2017 (European Commission, 2018). In Fig. 3 is reported a time series of year-on-year growth rates of the number of consignments transported and the tonne-kilometres realised by UIRR members over the years. The UIRR (*International Union for Road-Rail Combined Transport*) is the association for the sector of Combined Transport in Brussels which includes CT operators and CT terminals. The results proposed by UIRR based on the traffic of its operator members show that the European Combined Transport closed a year of robust growth in 2017: the total number of consignments increased by +5.48% (expressed in tonne-kilometres grew by +8.7%).

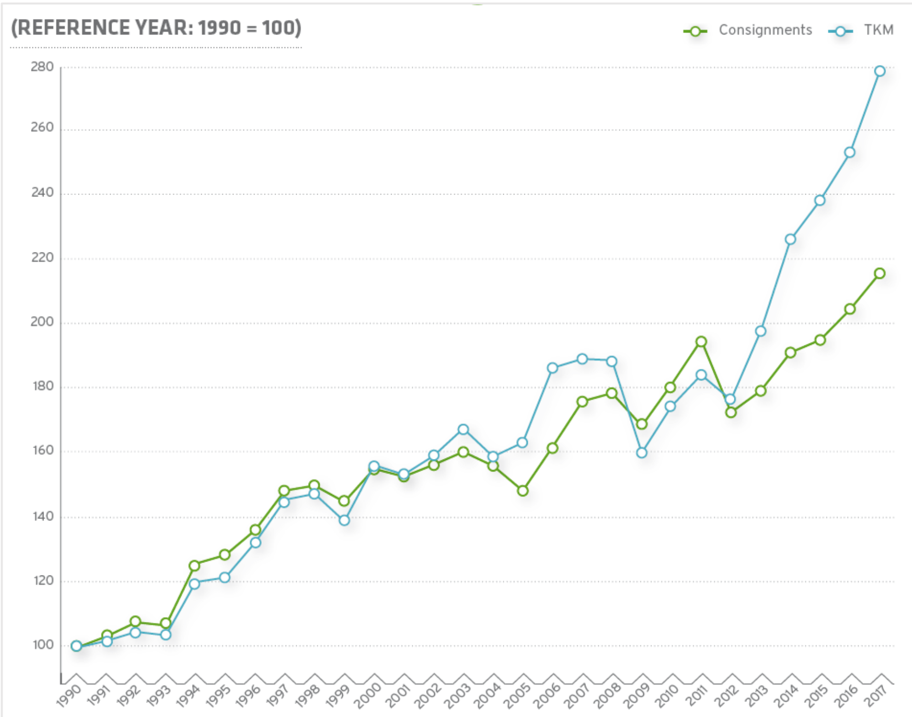


Fig. 3 UIRR CT Growth Index - Consignments and Tonne-Kilometres (UIRR, 2018)

1.2 Regulation framework

The regulations framework is fundamental to propose and evaluate the competitiveness of rail-road combined transport and the effect of ITS applications on intermodal terminals. The legislation may provide general guidance and inputs during the research activities to propose solutions in touch with the times. In the following the main legislative references.

- The European Union, in the *European White Paper on transport 2011*, has reiterated the need of reduce drastically the greenhouse gas emissions worldwide with the goal of maintain the global warming under 2°C. In total, by 2050, Europe must reduce emissions by 80-95% compared to 1990 levels (European Commission, 2011). The White Paper further states that freight transport over short and medium distances (roughly below 300 km) will continue to be carried, in large measure, with trucks. In longer distances, options for road decarbonisation are more limited, and freight multimodality must become economically attractive for shippers. Thirty per cent of road freight over 300 km should shift to other modes such as rail or waterborne transport by 2030, and more than 50% by 2050, facilitated by efficient and green freight corridors. Intermodal transport might be a good solution to achieve these recommendations, since rail transport, in most cases, does not allow door-to-door transport.

- The *2030 climate and energy framework* set three key targets: 40% cuts in greenhouse gas emissions (from 1990 levels), 27% share for renewable energy and 27% improvement in energy efficiency. The aim of the strategy is to send a strong signal to the market, encouraging private investment in new pipelines, electricity networks, and low-carbon technology. The targets were based on a thorough economic analysis measuring how to achieve decarbonization by 2050 in a cost-effective way.
- The *EN 13044 of 2011* (Intermodal loading units – Markings – Part 1: identification marks) defines the standard of Intermodal Transport Units (ITUs[1]) identification through a unique code, called ILU-Code (Fig. 4), which is compatible with the international BIC-Code, used for maritime containers (ISO 6346 of 1995). The International Union for Road-Rail Combined Transport (UIRR) from July 2011 started the dissemination of these codes via web. The specific tag has been designed to identify non-ISO containers[2], swap bodies and semi-trailers that take part in combined transport within Europe. After a transition period, from July 2019 all intermodal units through the Member States must be equipped with the codes specified in EN13044. In 2015 the penetration of consignments feature the ILU- or the BIC-Code was approx. 90% of unaccompanied combined transport (UIRR, 2015). These codes allow administrative and customs related operations, or similar transactions, to be facilitated and stringent safety rules to be met more easily; the ILU and BIC codes are written in clearly visible characters, which are recognizable by Optical Character Recognition (OCR) automatic systems. The intermodal terminals may be facilitated by this standard, because thanks to specific instrumentations may manage automatically the gate in and gate out phases (i.e. identification process).

Owner-key - Registration number - Check digit ABCA 001234 2	
Owner-key:	Allocation by UIRR or BIC 4th alpha character for type of loading unit [5]
Registration number:	Free allocation by owner
Check digit:	Given calculation procedure

Fig. 4 Example of an ILU-Code application. (Dalla Chiara, Deflorio, & Carboni, 2017)

[1] *Intermodal Transport Unit:* a rigid and crushproof structure, generally unified in size and in some of its components, which is suitable for the containment and protection of goods and for mechanical transfer between different modes of transport (Dalla Chiara, 2015). The most common solutions are containers, which were created in particular for maritime transport, as well as swap bodies and semi-trailers, which are suitable for rail-road transport.

[2] The current standard for maritime containers is the ISO 6346 standard, which is used worldwide to describe the BIC-Code allocated by the “Bureau International de Containers”.

- The Commission *Regulation (EU) No 1305/2014* of 11 December 2014 on the technical specification for interoperability relating to the telematics applications for freight subsystem of the rail system in the European Union (TAF TSI) has the aim to ensure the efficient interchange of information through the actors involved in the transport process. It covers the applications for freight services and the management of connections with other modes of transport. The TSI for Telematics Applications subsystem for freight services defines the required information, which must be exchanged between the different partners involved in a transport chain and permits a standard mandatory data exchange process to be installed. In addition, the regulation reports in paragraph 4.2.11.2: "For intermodal transport, the data messages containing the identifiers of the loading units (e.g. containers, swap-bodies, semi-trailers) will use either a BIC- or an ILU-Code according to ISO 6346 and EN 13044 respectively."
- *Regulation (EU) No. 913/2010* concerning a European rail network for competitive freight (Fig. 5). This Regulation requires Member States to establish international market-oriented Rail Freight Corridors (RFCs) to meet three main challenges: strengthening co-operation between infrastructure managers on key aspects such as the allocation of paths, deployment of interoperable systems and infrastructure development; finding the right balance between freight and passenger traffic along the Rail Freight Corridors (RFCs), giving adequate capacity for freight in line with market needs and ensuring that common punctuality targets for freight trains are met; promoting intermodality between rail and other transport modes by integrating terminals into the corridor management process. Freight corridor means "all designated railway lines, including railway ferry lines, on the territory of or between Member States, and, where appropriate, European third countries, linking two or more terminals, along a principal route and, where appropriate, diversionary routes and sections connecting them, including the railway infrastructure and its equipment and relevant rail services in accordance with Article 5 of Directive 2001/14/EC" (European Union, 2010).

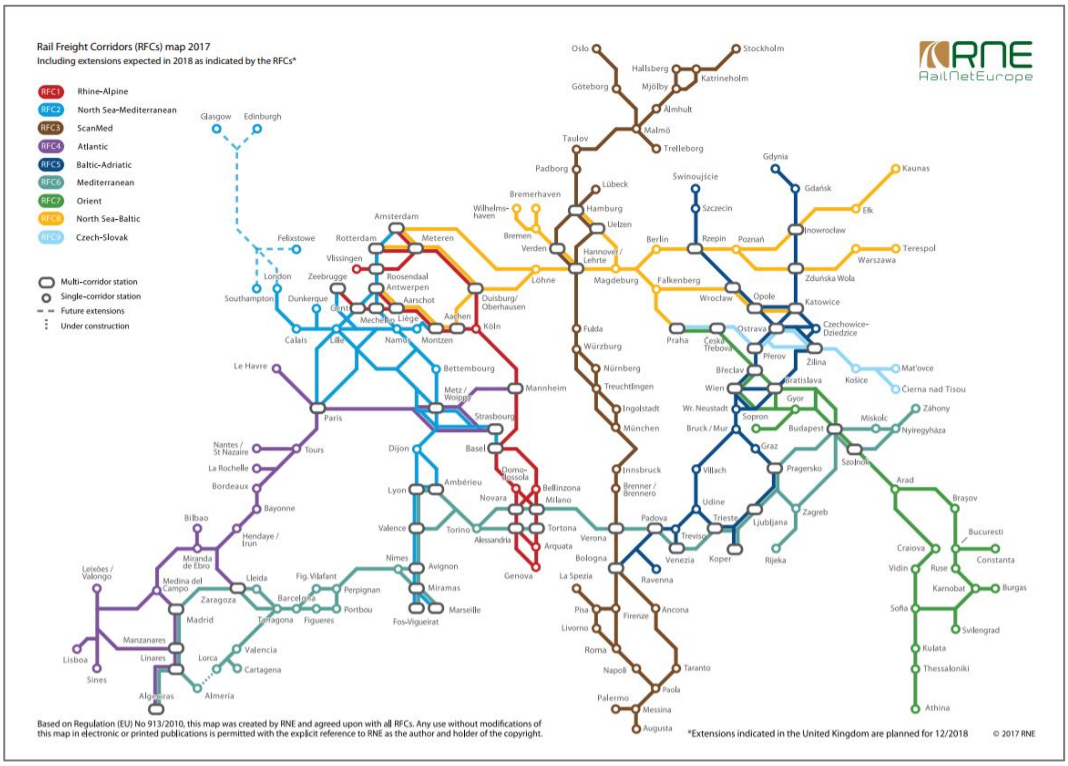


Fig. 5 Rail freight corridors 2017 (http://www.rne.eu/rail-freight-corridors/rail-freightcorridors-general-information/)

1.3 Literature review

The growth in the number of published papers on intermodal freight transport from 2000 onwards was presented through an historical literature review by Agamez-Arias & Moyano-Fuentes (2017) and by Mathisen & Hanssen (2014). The first paper identified three main lines of research very similar to the issues covered in this thesis: basic principles of intermodal transport, improvements for intermodal transport and variables which impact on its efficiency and intermodal transport modelling. The second paper attributed the increase of articles on intermodal transport to the intense political focus on this topic (as already stated in the introductory sections of this thesis). An interesting literature review on intermodal transport research is presented by also Macharis & Bontekoning (2004) to investigate how and which operational research techniques can support this branch of research. In fact operation research is one of the main research fields, with computer science, maritime, transportation and others, identified by Dragović, Tzannatos, & Park (2017) after a detailed review of the available research literature on the application of simulation models in port development. The port context certainly has some common characteristics with the rail-road terminals, even if not completely. More generally, the recent relevant literature, including 89 papers from 2007 and 2017, concerning simulation models applied to intermodal freight transportation is presented in the paper by Crainic, Perboli, & Rosano (2018).

In the following sections relevant research papers on main topics covered in this thesis are collected: the role of combined transport as sustainable and competitive solution for freight transport and possible improvements as ICT implementations (§1.3.1), the economic analysis of intermodal transport including external costs and the importance of terminal locations which influence the length of pre/post haulage covered by road for instance (§1.3.2), the different approach to model intermodal terminal (§1.3.3) and the main performance indicators (§1.3.4).

1.3.1 Competitiveness of freight combined transport and the role of technologies

Railroads are the most environmentally sound way to move freight over land (Association of American Railroads, 2017) and can be a strategy for climate change mitigation as showed by Pinto, Mistage, Bilotta, & Helmers (2018). Their results demonstrated that road-rail intermodal operations can be up to 77.4% less polluting than operating solely with road transport. Calculate the greenhouse gas emissions from transportation may not always be simple, Craig, Blanco, & Shef (2013) analysed a data set of more than 400,000 intermodal shipments to calculate the CO_2 emissions of intermodal transportation and give also a guidance for shippers. The authors estimated the average carbon intensity of intermodal transport around 70 g CO_2 per ton-mile, 44% lower than truckload. The effect of taking into account environmental considerations into freight intermodal transportation planning was addressed by Bauer, Bektaş, & Crainic (2010). While Zumerchik, Sr, & Rodrigue (2011) proposed an energy-based freight efficiency analysis for intermodal transport system, in detail they covered three aspects also taken up in the following chapters: line haul, modal transfer, and storage components. As regards the modal transfer, for instance, Geerlings & van Duin (2011) developed a method to understand the CO_2 emissions by container terminals in port areas and identify the most effective solutions of reducing them. Since the transhipment of containers takes place with the different types of equipment, their model focus on the terminal equipment performance unlike this thesis where the terminal energy analysis focuses on truck flow emissions (section 3.4.2).

The effect of transport policies in Europe, for instance the internalization of the external costs is proposed by Santos, Limbourg, & Carreira (2015) with a an innovative mixed integer intermodal freight location-allocation model based on the hub-location theory applied in a case study in Belgium. Similar case study is used by M. Mostert, Caris, & Limbourg (2017) analysing the effect on modal split between road, intermodal rail and intermodal inland waterway transport of several economic or environmental policies. Besides, the indications of the EU's White Paper 2011 are the starting point for the work by Islam, Ricci, & Nelldal (2016) and Wagener (2014) that analysed the modal shift from road to rail. The first paper indicated some implementations, including the operation of heavier and longer trains, wider loading gauges, higher average speeds, and a better utilisation of wagon space, for railway transport in order to be able to offer a competitive service. The second one suggested other implementation: multimodal operation in maritime hinterland transportation, innovative handling technologies and freight corridors for long distance intermodal transport within the TEN-T network and on the Europe-Asia corridor. Implementations for improving intermodal freight transport were also studied by Skočibušić, Stupalo, & Sanja (2011) on the basis of literature review. Among the aspects that they proposed there is an ICT solution to improve efficiency, as proposed in this thesis. At European level the trend is a major efforts in ICT developments in freight intermodal transport as confirmed by Harris, Wang, & Wang (2015). In line with this, Mahdavi (2018) identified the factors that can encourage or discourage ICT adoption among intermodal freight transport companies. These factors include the cost-benefit analysis as also emerged in other articles. In general, infrastructure and technological improvements should be combined to increase the competitiveness of intermodal transport as stated by Binsbergen, Tavasszy, & Duin (2014) and also addressed in the thesis. Wichser, Weidmann, & Nash (2007) affirmed that in addition to improving the performance of infrastructures, the management of intermodal transport must be consolidated to improve the quality of intermodal transport. Evers & Johnson (2001) underlined that the competitiveness of rail-road combined transport may be influenced by the shipper's overall perception of the intermodal service and ICTs could improve it.

In the context of intermodal transport management, for example Macário & Reis (2008) stated that adequate information system is of paramount importance in the success of intermodal transportation. The benefits of information sharing are considerable according Leviakangas, Haajanen, & Alaruikka (2007). The authors have developed an information service architecture for the international multimodal logistic corridor. By the way, the economic impacts of telematics services in freight transport is important, Mbiydzenyuy, Persson, Davidsson, & Clemedtson (2012) proposed a wider overview of this topic.

Again, on the technological improvements, the ICT (Information and Communication Technologies) supports for intermodal terminal operations are interesting issue, often addressed in literature in seaport context (Bohari & Zainuddin, 2013) (Cimino et al., 2017) (Schøyen, Hjelmervik, Wang, & Osen, 2017) (Alessandri, Sacone, & Siri, 2004). Chen et al., (2016) for instance proposed the GPS ship traces, the Automatic Identification System (as Liu, Sheu, & Chen (2015)) and maritime open data to derive port performance indicators, including ship traffic, container throughput, berth utilization, and terminal productivity. Shi, Tao, & Voß (2011) instead have evaluated a RFID application for operational procedures in port-based container logistics. Important sub-process in terminal process is the units and vehicles identification, especially during the gate operations. The automatic identification systems have been developed for monitoring of units flows in order to improve the identification process efficiency (Yoon, Ban, Yoon, & Kim, 2016).

A practical implementation of technologies is presented in this thesis with an on-field intermodal terminal monitoring (section 3.4.3). In particular the main focus is on the application of Bluetooth and Wi-Fi sensors to track and trace the vehicles inside the terminal area. The increased number of literatures which have reported on the use of Bluetooth data as a complementary traffic data source is due to the fact that the Bluetooth communication has become widespread in many on-board devices, such as headsets, car navigation systems and smartphones (Tsubota & Yoshii, 2017). Several authors have investigated, also thanks to field observations, the positive and negative features of traffic detection with Bluetooth sensors and the main aspects which could influence the measure (Tsubota & Yoshii, 2017) (Kitazawa, Shiomi, Tanabe, Suga, & Hagihara, 2014) (Nishiuchi, Shiomi, Kurauchi, Yoshii, & Suga, 2015). Abedi, Bhaskar, & Chung (2013) for example have identified the antenna type as one of the factors that may affect the quality of data collection. Moreover, their work was useful to evaluate the features of sensors used in the application proposed in this thesis. As regards the post data elaborations, the process proposed in section 3.4.3 is quite similar to one shown by Abbott-Jard, Shah, & Bhaskar (2013) even if the assumptions and the algorithm are different. They also said that integrate data from both Bluetooth and Wi-Fi sensors, as happened in our monitoring phase, should increase the sample size.

First of all, the view of intermodal transport system is required to evaluate its technical and economic range of competitiveness, as proposed for example by Flodén (2009) within the MINT Project (Model and decision support system for evaluation of intermodal terminal networks). The author reports an interesting list of activities for intermodal transport system and related actors involved using tables and conceptual model, unlike this thesis where Standard Language as *Unified Modeling Language* is used.

Nevertheless, an analysis of combined transport freight transport with a focus on main Italian rail terminals and their characteristic was conducted by Lupi, Pratelli, Giachetti, & Farina (2018). In order to achieve a satisfactory modal shift towards intermodal transport they suggested an improvement of rail connections efficiency. Among their outcomes, they underlined the possible convenience of intermodal transport also over short distance as in the case of port and dry port connection due to the elimination of the pre-haulage and related operations, as will be seen from the section 2.2.5. Bärthel & Woxenius (2004) otherwise used a technological systems approach to evaluate the development of intermodal transport for small flows over short distances. They obtained that the diffusion is hampered by several factor as insufficient network connectivity. Crainic, Dell'Olmo, Ricciardi, & Sgalambro (2015) also have covered the issue, so large flows over short distances, specifically they design a network model to plan a shuttle service between dry port and seaport. The competitiveness of railway on short distance, especially in the case of dry port-seaport connection, is an interesting research topic (Bureau of Infrastructure Transport and Regional Economics (BITRE), 2016) (Ambrosino, Ferrari, Sciomachen, & Tei, 2016) (Zhang & Pel, 2016) (Harder & Smith, 2018) (Ambrosino & Sciomachen, 2011) (Ferrari, Parola, & Gattorna, 2011) (Jeevan, Chen, & Cahoon, 2018). The last one for example investigated the impact of dry port operations on container seaport competitiveness. Among the possible exceptions which can influence the range of convenience of combined transport there is for instance the case of longer and heavier vehicles for road transport (Ye, Shen, & Bergqvist, 2014)(International Transport Forum, 2017).

The competitiveness of intermodal transport is related to the stakeholders' perception, as underlined before. Often, there is a gap between supply and demand, in this sense Macharis, Vanhaverbeke, van Lier, Pekin, & Meers (2012) proposed as possible solution a web-based tool in which companies can check if intermodal transport could be a good alternative. Also Prata & Arsenio (2017) considering the views of the port stakeholders in the transport alternative choices and obtained that the critical variables are the reduction of shipping speed and CO_2 emissions.

1.3.2 Economic analysis of intermodal transport

Two fundamental variables in the choice of freight transport modes are costs and time (Agamez-Arias & Moyano-Fuentes, 2017). In this thesis the costs are taken into account during the economic analysis of intermodal transport while the time plays an important role in the intermodal terminal evaluation.

The transfer to rail-road combined transport could occur if the price of the combined alternative were attractive, for instance Frémont & Franc (2010), according to the operators, asserted that the price would need to be 10-20% lower than the road solution. Kordnejad (2014) stated that the intermodal transport can save around the 20% of transport cost. Their results identified the loading space utilization of the train and the cost for terminal handling as the most critical parameters for intermodal system. Whereas Larranaga, Arellana, & Senna (2017) using a simulation of the freight transport in Rio Grande do Sul (Brazil), suggested investments to increase the reliability of intermodal alternatives because are more effective than cost reductions. In this thesis some technical and economic considerations are reported in Chapter 2 to compare rail-road solution to road one.

The comparison between the total costs of road and rail-road combined transport using Janic's formulas is proposed by Kos, Vukić, & Brčić (2017). They presented the total trend of costs changing the pre and post distances covered by road but compared to the graphs proposed in section 2.2.3, it does not show the details of the individual cost components (road, rail, terminal transhipment...). Whereas detailed comments and considerations about each component of rail-road combined transport costs are reported in Dalla Chiara & Pellicelli (2011). The authors proposed formulas and qualitative graphs which have constituted the basis of section 2.2.3.

Hanssen, Mathisen, & Jørgensen (2012) proposed a complex model to evaluate the generalized costs of intermodal freight transport. In this thesis, by means of a simpler method, similar aspects are investigated, and the results obtained are similar. For example, they said that when the handling costs in the terminals increase, the total transport distance increases, the pre- and post-haulage costs increase, the distance-dependent marginal generalized costs for rail increase, the distance-dependent marginal generalized costs for trucks decrease and the resting costs for truck drivers reduce necessarily the distance covered by the alternative mode should increase. The results are in line with the results of the model proposed by Bína, Bínová, Březina, Kumpošt, & Padělek, (2014), in addition they obtained that the price is more important than the time for a shipping of the most of the cargo and therefore also the combined transport solution could be a good alternative.

Then, Ye, Shen, & Bergqvist (2014) developed a cost calculation model for investigating the potential of longer and heavier vehicles for pre- and post-haulage in the intermodal transport chain. Their results show that these improvements can increase the competitiveness of combined transport due to the increase of efficiency, decrease of total energy consumption and emissions.

Kim & Van Wee (2011) also analysed the factors which can impact on the break-even distance between combined transport and road alternative. They used a Monte Carlo-based model evaluating similar aspects such as the distance covered by all modes, the terminal locations and the terminal handling rates. These are key elements also in this work.

Flodén (2011); Al Enezy, van Hassel, Sys, & Vanelslander (2017); (Kordnejad, 2014); (Yao-rong, Ming, & Yue, 2009) covered the topic of freight cost calculations, especially of intermodal transport in different ways. Sahin et al. (2014) proposed different intermodal transportation model based on cost analysis including various technical, economical, and operational parameters. After comparing several intermodal options, as sea-road, sea-railway, road-railway, and multimode of sea-road-railway, they obtained the convenience interval for the solutions. For example, the railway-road intermodal transportation becomes more economic than single road transportation when the route distance is greater than 1200 km because the handling costs are determinant factor; the obtained distance interval is not very common to those present in the literature.

The market structure in the intermodal freight transport is addressed in the paper by Saeedi, Wiegmans, Behdani, & Zuidwijk (2017), in particular their main challenge was the definition of the geographical market for terminals that are competing inside a transhipment submarket. Likewise, Pekin, Macharis, Meers, & Rietveld (2013) developed a model to analyse the market areas of existing and potential intermodal terminals in Belgium.

The terminal location is an issue also proposed by Limbourg & Jourquin (2008), Sirikijpanichkul & Ferreira (2005) and Carreira et al. (2012). Two aspects are considered using an iterative procedure based on the p-hub median problem by the first paper: the variation of transhipment costs according to the number of transhipped intermodal transport units and the terminal locations (through the pre- and post-haulage costs), as in this thesis. The second paper considered not only terminal owners' and users' benefits but also community impacts to evaluate the optimum location of terminals. They were able to do this with an appropriate multi-objective evaluation technique, similar to the multi-criteria decision approach for terminal location by Long & Grasman (2012). While Halim, Kwakkel, & Tavasszy, (2016) proposed a combination of a multi-objective optimization model and an assignment model, taking into account port-hinterland transport cost, port-hinterland transport time, and distribution center-hinterland transport time. The Weber model, the market areas theory and the facility location model allow to evaluate the best terminal location according to potential demand (Piccioni, Antoniazzi, & Musso, 2010). Lastly, Carreira et al. suggested an optimisation model for intermodal terminal position to evaluate how the catchment area of the terminal could change by including external costs. While Braekers, Heggen, & Crauwels (2018) used two approaches to evaluate the effect of terminal selection on the pre- and end-haulage costs: a straightforward analysis of direct distances and a more complex vehicle routing approach.

In this context, an interesting state of the art about external costs of freight transport propound by Mostert & Limbourg (2016), as well as Kreutzberger, Macharis, Vereecken, & Woxenius (2003), who presented an overview of the types of external costs and the methodologies that were used to estimate the external effects in terms of costs. CO_2 and other greenhouse gasses (GHG), noise and traffic accidents are included as social impact in the freight transport optimization model proposed by Zhang, Janic, & Tavasszy (2015). Same impacts are considered, excluding the accidents, in the cost calculation approach proposed in the following chapter. The impact of external costs (section 2.2.2) is treated also by Skočibušić et al. (2011) who consider research and innovation of new technologies necessary to reduce them. Again on the role of externalities, the above-mentioned formulas by Janic (2007) are used in the model by Kos et al., (2017) which calculate the total costs of intermodal freight transport network, composed by several origins and destinations and two main intermodal terminals, including time components. Since the results are related to the door-to-door distance the impact of the terminal location and so the role of pre- and post-haulage by road did not emerge. An important aspect come up namely that the total costs decrease more than proportionally as the door-to-door distance growths, suggesting economies of scale.

1.3.3 Intermodal terminal model

The second main aspects of this thesis are the intermodal terminal due to its fundamental role for the competitiveness of rail-road combined transport. In fact, as shown in the paper by Zajac & Restel (2014) proper operation of the intermodal transport chain depends on the proper functioning of the terminals, including their ability to perform cost- effectiveness, quality and reliability. Nevertheless, the literature review by Wiegmans & Behdani (2018) showed that handling costs play a marginal role in the scientific research in intermodal rail freight terminals.

By the way, Ballis (2004) besides providing interesting typical cost versus volume curve for intermodal terminals, analysed the influence of the quality of the service in their operations. The author provided a set of standards that would be useful for investment strategies and terminal design. The effects of terminal costs on freight transport network is shown in the paper by Behrends & Flodén (2012) in the case of intermodal line-trains. Their case study considered path with several terminals but without road haulage unlike the work proposed in the next chapters. They confirm common literature results: if the transhipment costs are kept low, the intermodal solution can be a competitive alternative over short and medium transport distances. The European Project IQ – Intermodal Quality estimated that on average, terminal operation accounts for 7% of the total cost of the transport chain (INRETS, 2000).

Thus, to better understand the role of intermodal terminal it is significant to know its internal aspects, as will be dealt with in the third chapter. Optimize the intermodal terminal process is an interesting issue explored by scientific literature.

Dotoli, Epicoco, Falagario, Seatzu, & Turchiano (2017) proposed a decision support system to allow the optimal train composition and load planning and the optimal storage of containers in the terminal yard. The first aspect was previously presented by Dotoli, Epicoco, Falagario, Angelico, & Vinciullo (2015) through an optimization model which take into account important aspects as the physical characteristics, priority and destinations of containers and wagons. The problem of containers scheduling and resources allocation could be optimized thanks to the solution proposed by Gambardella, Mastrolilli, Rizzoli, & Zaffalon (2001). Whereas Colombaroni, Fusco, Isaenko, & Quadrifoglio (2017) proposed a procedure for the optimization of the reshuffles of ITUs at an inland terminal carried out by two genetic algorithms that work in series.

In this thesis the attention is not on the rail-road terminal's process optimization, but above all it aims to evaluate the effect of technological implementations also in different scenarios.

As regards the model of rail-road combined transport terminal, for example Mangone & Ricci (2014) developed a model by a discrete events software to evaluate the effect of the units' tracking. Their focus concerns the identification operations during the gate in an Italian terminal, as the approach proposed in chapter 3, but the implemented solutions and the kind of simulation are different. In fact, they examined the introduction of a totem that provide badges to incoming drivers after identification and their results reveal that as a consequence the entry queue decrease. A discrete event simulation model is used also in by Baldassarra, Impastato, & Ricci, (2010) and Rizzoli, Fornara, & Gambardella (2002). The first model reproduced the activities carried out inside an intermodal terminal, to calculate the total transit time and to identify the bottlenecks. The second paper reported a discrete-event simulation model, using *MODSIMIII*, with the main terminal components, as road and rail gate, the platforms and the storage area, to calculate the terminal throughput.

In the same way, Dotoli et al. (2014) also used a discrete event approach to model the intermodal freight terminal in a timed Petri net framework. The authors shown the model effectiveness in evaluating the system performance and identifying its bottlenecks. Zehendner & Feillet (2014) ran experiments with an optimization model and again a discrete-event simulation model to evaluate the benefits of a truck appointment system, similar to the work by Zhao & Goodchild (2010). Other applications of discrete event simulation software are reported in the paper by Mathias, Santos, & Soares (2018) where the model is used to study the flows of cargo and equipment along the container terminal, identifying bottlenecks in specific areas and it was applied in the Port of Leixoes.

To compare several scenarios with different technological improvements, among the objectives of this thesis, the approaches proposed in literature tend to vary. An interesting research work presented by Ricci, Capodilupo, Mueller, Karl, & Schneberger (2016) within the European project Capacity4Rail suggested an approach in line with the topics of this thesis. To compare some terminal scenarios with different process implementations they used both analytical and simulation methods. The results, reported using some performance indicators, show the positive effects of innovations in the terminal efficiency, consistent with the conclusions reported in this work.

The modelling approach by Ballis & Golias (2002 and 2004) is based on an expert system, a train/truck arrival generator, a terminal simulation module and a cost calculation module to make a comparative evaluation of selected conventional and advanced technologies. These are especially regarding handling equipment, while the focus of this thesis is on the identification process. The results are reported in terms of cost and volume curves, excluding other indicators, for a given railroad terminal. They state a shareable conclusion: the alternatives should be chosen based on both costs and performance attributes.

Marchet, Perotti, & Mangiaracina (2012) presented a parametric model to assess the impacts of ICT applications in terms of time and costs on company freight transportation processes. Their scenarios were built based on a combination of applications in three areas: document management (as Electronic Data Interchange for document management), operations management (as identification systems, tracking and tracing) and safety and security management (as monitoring systems). A model in a Petri net framework by Dotoli, Fanti, Mangini, Stecco, & Ukovich (2010) shown that integrating ICT into the intermodal freight system leads to a more efficient management, in terms of system resources utilization and overall cost index.

Whereas Cimino et al. (2017) have discussed an approach for evaluating the impact of ICT technologies (RFID and WSN) on a harbour's logistics by BPMN *(Business Process Model and Notation)* modelling and simulation. In the same way Caceres, Mendoza, Tuñón, Rabelo, & Pastrana (2015) has used BPMN method to support identification and visualization of the container ship process. They proposed a discrete event simulation to generate some performance indicators (e.g. service time), but they do not deal with different scenarios or technological implementations.

Different approach to model intermodal terminal (graphical simulation software) is proposed by Dalla Chiara, Marino (2013) to evaluate terminal performance also including a failure analysis in the case of crane downtime. Still different is the simulation software used by Mosca, Mattera, & Saccaro (2018) which is *Flexsim CT*, a Visual Object Oriented program, considered for the simulation of dynamic systems. The authors divided the container terminal in sectors: the berth (for ship transhipment), the railway, the gate and the yard (for the storage). They studied different scenarios by varying the type of equipment and compared them with several performance indicators as queue and waiting time for trucks and trains. Or again Martínez, Gutiérrez, Oliveira, & Bedia (2004) proposed a simulation model, tested in the Port-Bou terminal, to the transfer of cargo between trains at rail terminals. They propose several scenarios by varying gantry crane operation modes to explore critical factors.

The approach proposed in this thesis to estimate the performance of rail-road terminal is based on microscopic simulation (section 3.4.2) as the example proposed for maritime terminals by Barcelo, Grzybowska, & Pardo (2005) even if the goals and the method are quite different the tool are the same. A micro-simulation model using *Paramics* tool is also presented by Lee, Wu, & Jin (2012) to model the truck movements within the port area. They examined different scenarios by changing the transportation demand, as proposed in this thesis, and provided a decision support system to determine the yard truck fleet size to optimize the transhipment operations. Same tool is used in the report by Cao, Golias, & Karafa (2013) where the focus is on the maritime terminal gates due to its contribution on the congestion problem during certain hours of the day. They also underlined the link between the gate issue with environmental effects stemming from idling trucks. Moreover, the authors proposed different strategies for gate operations such as a gate appointment system, extended hours of operations for terminal gates, and advanced technologies for gates and terminals. Thus, conceptually the approach proposed, the issue and the focus are like those reported herein but the context, the level of detail and the tool are different.

1.3.4 Performance indicators

The performance attributes of intermodal terminal, which are often important outputs of several simulation or analytic models, can be measured with defined performance indicators, as report in section 3.2.

For instance, the project Intermodel (Martín, Dombriz, & Soley, 2017) proposed a comprehensive literature review about the key performance indicators for intermodal freight transport. In particular the authors report an interesting classification of performance indicators, slightly different from the one proposed for example in Table 8, but the methodology is quite similar. In fact, its method of indicators selection is: identification of the strategy and mission, identification of stakeholders, identification of different perspectives, identification of strategic goals and selection of effectiveness criteria and feasible indicators set. This is referred to the entire terminal process, without the possibility to screen locally for example the single terminal operations. The approach adopted by Wang, Bilegan, Crainic, & Artiba (2014) is quite different, they suggested to select suitable performance indicators starting from the definition of specific problems and its framework. Although the paper context is the intermodal barge transportation systems some performance indicators defined for tactical planning are useful also for the case described in this thesis. Also Siciliano, Vaghi, Ruesch, & Abel, (2006) classified quality and performance indicators for inland terminals in relation to the actors involved and their measurability. In the European context they proposed a possible benchmark analysis for intermodal terminals underling the problem of comparability. In fact, the indicator may be related to some features as terminal process or dimensions otherwise the comparison between different terminals may not always be reliable. Define detailed terminal classification should help to reduce this distortion effect of comparative analysis. The issue of identifying appropriate benchmarks to assess the efficiency of transport chains was investigated also by the Intermodal Freight Transport Advisory Group (OECD, 2002). The main goal of Antognoli et al., (2018) was find methods, like analytical and discrete events simulation models, suitable to evaluate the performances of different types of rail freight terminals, as rail to road, rail to rail and rail to waterways. Similar to the approach proposed in this thesis, Morales-Fusco, Martín, & Soley (2017) proposed a set of indicators for intermodal terminal to evaluate: the performance of terminal operations from both technical and economical point of view; the external effects as regards to sustainable, safety and environmental terms; and the financial requirements from the investor/management point of view. The authors also provided a classification of them based on stakeholders, goal and categories but they do not split them according to the process operations and do not give measurement indications. Garcìa (2016) through a simulation tool compared several rail-road terminals in order to analyse different performances. This paper has contributed to the definition of the set of indicators proposed in section 3.2 whilst it does not address the issue of technological implementations.

Chapter 2

Rail-road combined transport chain

In the first chapter the framework of the research activities covered in this thesis is described thanks to the main definitions of intermodal freight transport, the important regulations and best practices and the current research situation about the principal topics explored. In this second the focus is on the rail-road combined transport which is an intermodal solution for freight transport with two transport modes. Starting from the typical supply chain processes an analytical approach to evaluate the technical and economic competitiveness of intermodal solution is shown. The main results are stressed considering some exception as the dry-port and sea port rail connection. The considerations can feed the typical modal split model components, introducing for instance energetic parameters.

In Fig. 6 the flow diagram to describe the methodology used in the following chapter is shown. The starting point is the intermodal freight process definition to identify the cost components of analytic formulas in order to compare alternative solutions. The outputs of the method are costs versus distance diagrams for rail-road combined transport and full-road alternative. Finally, some exceptions are investigated, as dry-port service and alternative fuel for road transport, modifying the comparison with new elements. The end point is the important role of intermodal terminals on rail-road combined transport competitiveness.

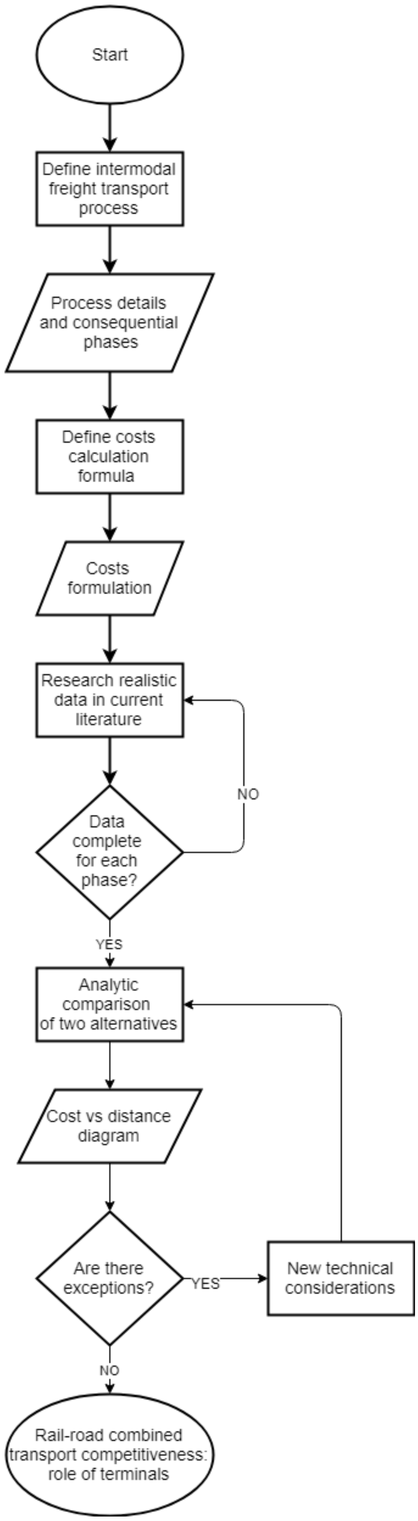


Fig. 6 Flow diagram of the method for assessing the rail-road combined transport competitiveness (Chapter 2)

2.1 **Rail-road combined transport typical processes**

The rail-road combined transport is an heterogenous solution for freight transport which involves several actors with respect to the unimodal solution. In this paragraph some representations of this complex process are presented to clarify the context.

The main phases can be synthetized as follow. The typical door-to-door combined transport may consist of (Fig. 7):

- initial road haulage (pre-haulage) from origin to intermodal terminal;
- operations in the starting terminal;
- haulage through the railway connection;
- operations in the arrival terminal;
- final road haulage (post-haulage) from intermodal terminal to destination.

The operations inside the intermodal terminal will be addressed in more detail below (section 3.1).

The main actors involved in the process are:

- *Senders,* who sends the goods.
- *Receivers,* who receives the goods.
- *Multimodal Transport Operator* concludes multimodal transport contracts; i.e., contract involving transport by more than one mode of carriage, and for which MTO accepts liability as a carrier. He offers transport services integrating the various transport phases by different modes in a single flow with a closed commercial offer.
- *Road carrier* provides transport of goods by road.
- *Railway undertaking* provides transport of goods by rail on the basis that the undertaking must ensure traction; this also includes undertakings which provide traction only (Directive 2001/14/EC).
- *Infrastructure manager* means some body or firm responsible for establishing, managing and maintaining railway infrastructure, including traffic management and control-command and signaling; the functions of the infrastructure manager on a network or part of a network may be allocated to different bodies or firms (Directive 2012/34/EU).
- *Terminal operator (terminal manager)* deals with the transshipment of the ITUs between the two modes and all that is related to them, from the entrance to the exit from the area of competence of the terminal.

Each carrier or actor could group different other actors which play particular roles during the sub-process. In this thesis due to its final aims only the main players will be considered.

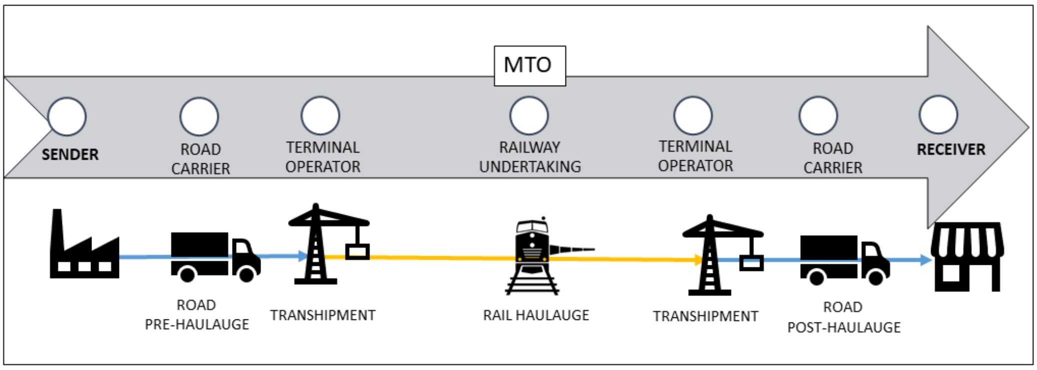


Fig. 7 Typical rail-road combined transport process and actors

In the following figures the typical rail-road combined transport process is described using the Unified Modelling Language (UML), which associates elements in different ways to form diagrams that represent a system. This language was originally specified as a modelling language for software development, but it has been used successfully in other areas as well (Weilkiens, 2008). The System Engineering, that is an interdisciplinary approach and means to enable the realization of successful systems, requires a standard language independently of specific disciplines. It integrates all the disciplines and specialty groups into a team effort forming a structured development process that proceeds from concept to production to operation[3]. The International Council of Systems Engineering (INCOSE) has been establish UML as a standard language for this discipline, calling it Systems Modelling Language (SysML) (Weilkiens, 2008).

In particular two kinds of diagrams are used below:

- in Fig. 8 a *Use Case Diagram* of a typical rail-road combined transport process is reported; this type of diagram provides a good high-level analysis from outside the system. Use case diagrams specify how the system interacts with the actors without worrying about the details of how that functionality is implemented. The shunting operations inside and near the terminal can be done by the railway undertaking or the terminal operators for instance, but in the following diagram this part is not considered.
- In Fig. 9 is shown an *Activity Diagram* that graphically represented operational workflows to show the activities of any part in the system for each actor.

The typical network of relationships between different actors reported in Fig. 8 and Fig. 9 underlines the complexity of intermodal terminal solution which requires robust organisation and efficient communication. The MTO assists the sender in the organization of transport by contacting the road carriers, the terminal operators and the railway undertaking to book and coordinate the respective parts of transport. Some actions are associated to more than one actor, for example the transshipment

[3] (https://www.incose.org/systems-engineering).

of ITU is the contact point between the road carrier and the terminal operator, this means that their operations should be as coordinated as possible to not compromise the efficiency of the whole system, i.e. combined road-rail transport. The transshipment of ITU is the contact point also between the second terminal operators and the railway undertaking who delivers the train. The management of connections with different modes of transport is important issue also covered in the TAF TSI (Regulation (EU) No 1305/2014) which has the aim of ensure an efficient exchange of information between actors to tracing and tracking the goods during the transport.

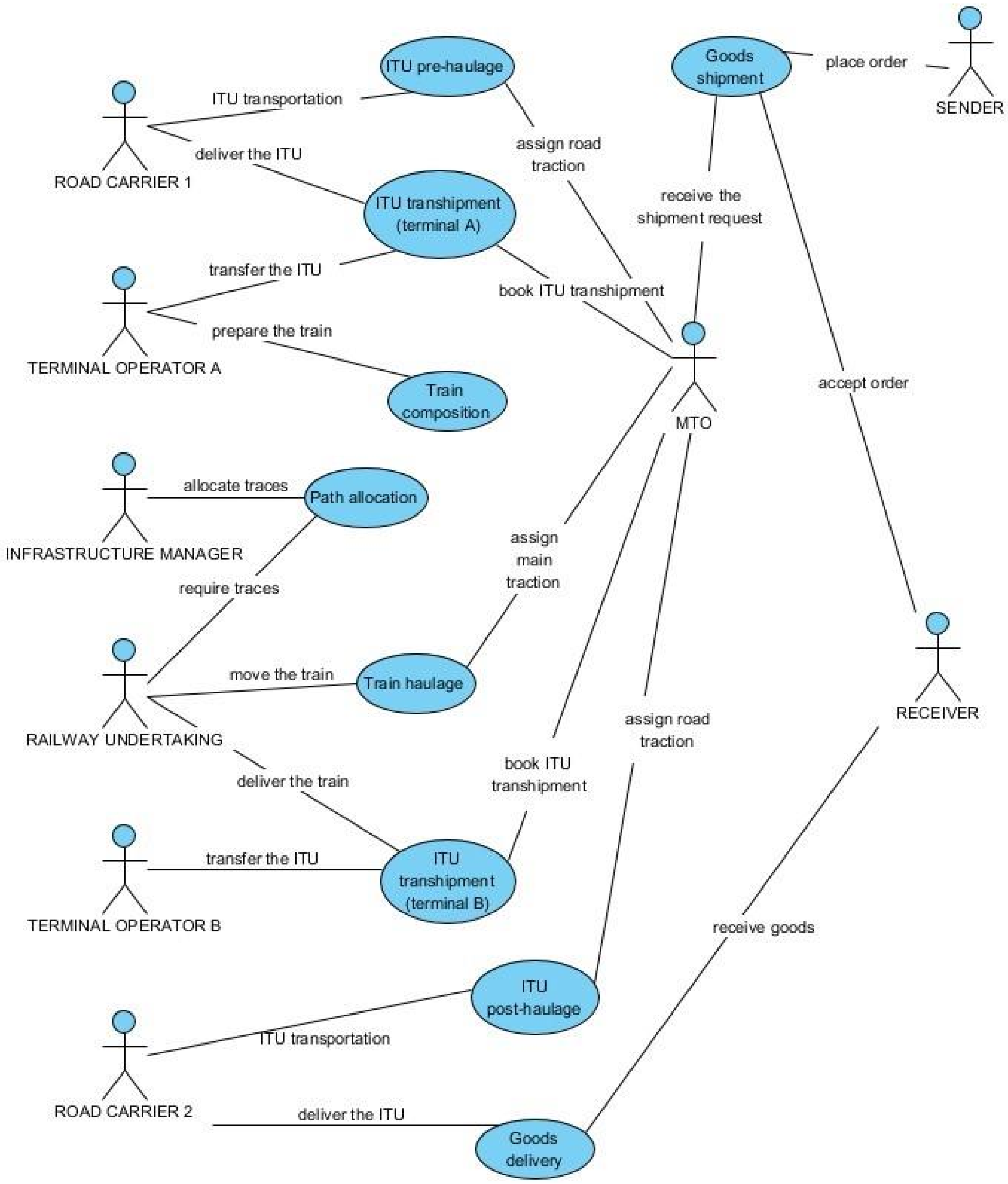


Fig. 8 Rail-road combined transport Use Case Diagram

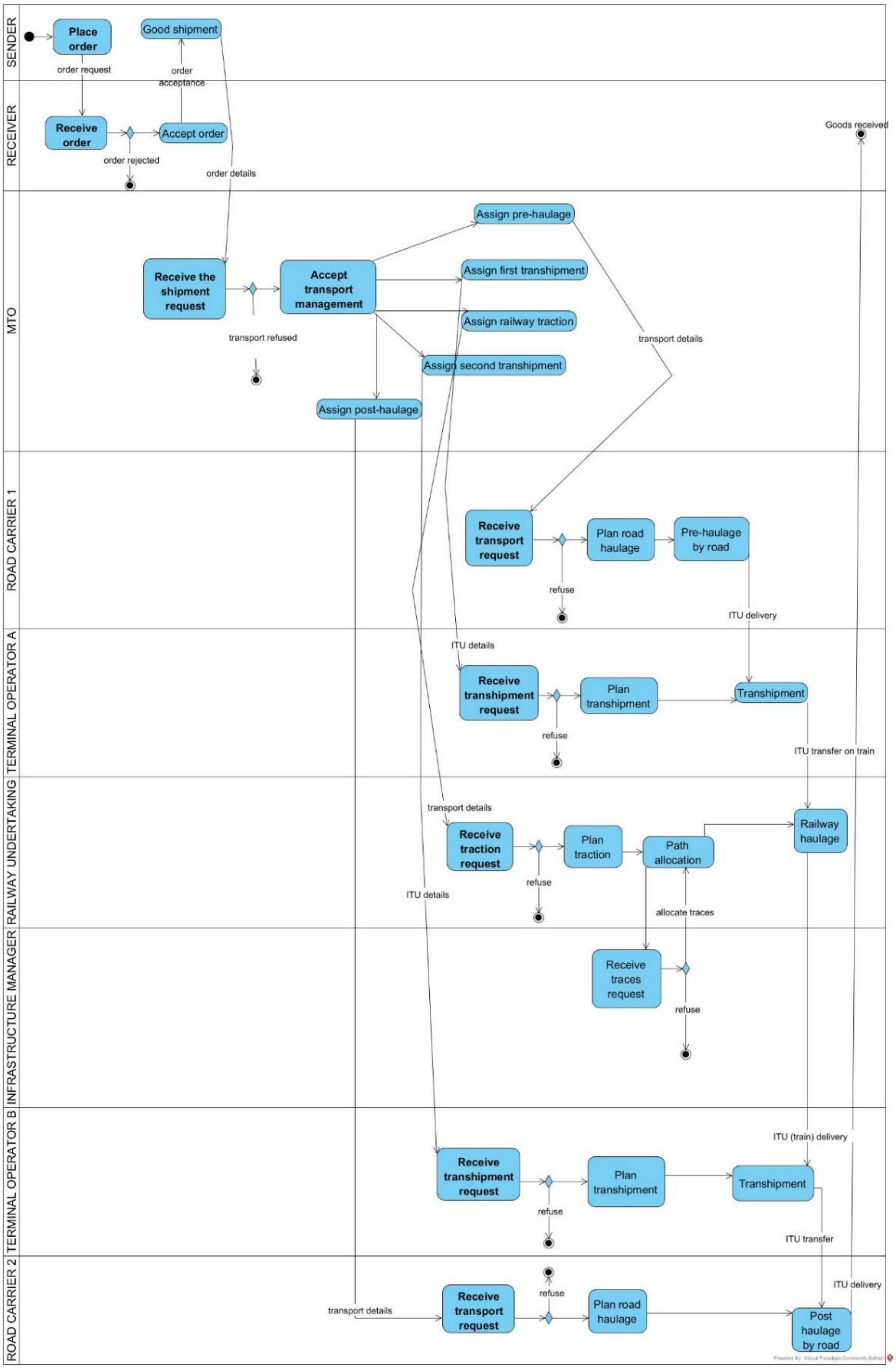


Fig. 9 Activity diagram of typical rail-road combined transport process (main actions)

2.2 Technical-economic competitiveness of combined transport

Part of the work discusses in the following section derive from the one presented in the paper by Carboni & Dalla Chiara (2018).

The range of technical and economic competitiveness of rail-road combined transport in terms of covered distance should be analysed to discover the market place of this solution. To achieve the aim, it is important to consider both the well-known range of convenience of different transport modes and the European environmental constraints that mainly affect the road sector. As mentioned before, the rail-road choice could be an environmentally friendly solution which contributes to avoid the problems of lack of flexibility of railway mode. Obviously, the evaluation of each part of transport chain is necessary to understand the total costs of rail-road combined transport. The interval of competitiveness is expressed in terms of covered distance using simple method, with realistic data, which allow a proper dissemination among the actors involved in the decision-making processes. To take into account the positive aspects of railways in terms of environment is appropriate to include also external costs in the analysis. The European Commission has also highlighted the need to establish a more efficient transport pricing, to better reflect the actual cost of transport. The research on external costs of freight transport has increased in the last few years, due to their increasing impact on the economy, environment, climate and society (Demir, Huang, Scholts, & Woensel, 2015).

If a general comparison is made between the composition costs of a road and railway vector, some technical asymmetries emerge. The characteristics of an infrastructure are: slow and rigid for railways, as regards freight, while road transport is frequently faster, in part thanks to the far wider capillarity of the road network and the possibility of avoiding two modal shifts. The latter is also possible rail, but only when shuttle trains from industry to industry are pursuable, in terms of quantity and availability of track links connected to the main railways (which are usually foreseen by the rail infrastructure manager for heavier traffic than 2-3 trains/week).

Haulage through the railway connection generally presents the lowest unit cost (per km), mainly because of the traffic concentration. On the other hand, the costs of the initial and final road haulage, although not directly dependent on the distance covered, could reach high amounts that may make combined transport vs. the full road choice unaffordable. In fact, road haulers run entrepreneurial activities whose daily costs are not always related to the covered distance, but which can depend on the number of services between the terminal and the place of origin they perform a day or the destination of the goods. Moreover, the road congestion of urban and suburban areas where they operate for the "last mile", discussed in greater depth in section 2.3, which is called also pre/post haulage or drayage[4], could involve

[4] Drayage is the transport of goods over a short distance via ground freight.

considerable additional time (and consequently additional costs). Again, in terms of timing, we should also add the time spent by the truck driver inside the intermodal terminal for the loading and unloading operations (*turnaround time*).

Pinto, Mistage, Bilotta, & Helmers (2018) have summarized these aspects as follow. The positive aspects of road transport are:

- reach, ability to deliver to most destinations;
- flexibility, capacity to operate on virtually any country's roads;
- speed, especially on short routes;
- low costs, due to simplified maintenance and handling requirements;
- low investment requirements.

However, there are inherent disadvantages, such as:

- susceptibility to traffic in urban environments;
- accidents or breakdowns due to exposure to poor road pavement or unfavourable weather;
- limited load capacity for business operations that require the displacement quantities of materials over long distances;
- high emissions of gases associated with climate change due to fuel combustion.

Railway mode do not have the same reach and flexibility as trucks, however, their characteristics allow the transport of great quantities of materials over long distances, and avoid most problems related to weather and traffic. These advantages come at higher investment and maintenance costs, however, trains' reliability and significantly lower fuel consumption per tonnes transported have placed this modal among the favoured alternatives to reduce atmospheric emissions derived from transport activities (Pinto, Mistage, Bilotta, & Helmers , 2018).

2.2.1 Internal costs

The operations of a rail-road combined transport chain[5], described in detail in section 0, usually involve the following main costs (Janic, 2007) (Dalla Chiara & Pellicelli, 2011) (Black, Seaton, Ricci, & Enei, 2003):

- initial road haulage (*pre- haulage*), with the related organisational costs, which are generally provided by road transport companies. These costs include the ownership and the use of vehicles, the use of the infrastructure (taxes, toll) and the costs generated by the down-time time during the loading and unloading operations;
- operations in the starting terminal;

[5] In this thesis, we have considered a *rail-road combined transport chain* for door-to-door transport, while goods consolidation and deconsolidation operations, that is, when goods are inside the transport unit, have been excluded.

- haulage through the railway connection, the costs of which are linked to the mode itself and to the use of the infrastructure;
- operations in the arrival terminal;
- final road haulage and the related organisational costs, such as pre-haulage;
- cost for the use of the Intermodal Transport Units (ITUs);
- cost for the use of railway wagons for the intermodal transport;
- organization and management costs of the railway operator.

The breakdown of the costs into their standard items allows a few common components to be defined:

- depreciation costs of all the instruments and means used along the intermodal transport chain;
- staff costs;
- consumption costs, that is, all of those costs that are required to provide fuel, oil, tyres and the necessary power for all the modes of transport;
- maintenance costs, which include the routine maintenance and repairs of the transport means (lorries, trucks, railway wagons, ships...) and loading units. This item does not include the infrastructures;
- insurance costs;
- taxes, which are paid on the purchase (or rental) and on the use of vehicles and ITUs;
- tolls, which are paid for the use of some infrastructures.

Some costs are not distance-related, as those concerning the handling operations and the management of ITUs in the starting and arrival terminals. The cost of the intermodal terminal includes depreciation and interest charges, maintenance (land, infrastructure and equipment), staff salaries, operating costs (energy, consumables, and general expenses), miscellaneous expenditure (insurance...) and taxes. It is commonplace to note that, if the terminal cost in the trend of total costs for freight transport affects the final cost to a great extent, the intermodal choice loses its attractiveness. Therefore, intermodal services, based on transhipment technologies that make it fast and efficient, can be sufficiently competitive in comparison to all-road medium and long distances. The improvements for intermodal terminal and its role are discussed below.

It is not easy to obtain intervals of costs for the different components of the freight transport chain, since economic and marketplace reasons frequently imply discretion. The RECORDIT Project, *REal COst Reduction of Door-to-door Intermodal Transport*, supported by a European Commission, defined some internal cost items (Black et al., 2003), which were also reported for example in (Kim & Van Wee, 2011). These values are considered for their comprehensiveness that allowed to cover all the defined cost items (internal and external one (§2.2.2)) with average realistic values. The following values are average values of European countries:

- *"road only" cost* → 0.58-1.37 €/km for an ITU (40'), with an assumed vehicle utilisation rate of 0.85;
- *pre- and post-haulage cost* → the cost is higher than the value for road haulage over long distances; it is in fact 1.23-3.78 €/km for an ITU (40'). This item, as stated above, does not usually depend on the distances, but the range of significant values is used for comparison purposes;
- *rail haul cost* → which is generally lower than the road cost, with an average range of between 0.46 and 1.35 €/km;
- *terminal cost* → the gateway movements involve an estimated cost of 27€ for an ITU (40'), instead, for the case of road-rail transfer, this amounts to from 36 to 60 €/ITU.

2.2.2 External costs

On average, rail-road combined transport result to be four to seven times more energy efficient than trucks: this is a direct consequence of the physical rolling resistance (~1.5÷8 k/kN for the rolling stock vs. at least ~15 N/kN for heavy duty vehicles). Subsequently, since greenhouse gas emissions are related to fuel consumption, moving goods by rail can reduce the GHG emissions by as much as 75%, according to (Association of American Railroads, 2017). This is especially true if the energy source is used in a different way in the two modes: in the former case, from oil-derived fuels, usually gasoil and usually through the electric grid and diversified primary sources in the latter one. According to Horn and Nemoto (2005), intermodal freight transport in Europe results in 60-80% fewer accidents and 40-50% lower CO_2 emissions than road transport; the overall social cost saving is 33-72%, compared to road transport, and an external cost saving of 1 Euro for 85 t-km shifted from road to rail, for 52 t-km shifted to an inland waterway and for 50 t-km shifted to coastal shipping. According to our analyses, the consumption and emission trends for the case of rail-road combined transport presents a similar structure to that of costs, that is, discontinuous due to the presence of terminals.

Therefore, the evident advantages of intermodal transport mainly result to be related to the decrease in external costs. According to Mathisen & Hanssen (2014), with their hypotheses, this result to be just 28% (per ton-km) of the external costs involved in road haulage, and this gap tends to be greater if the calculations include costs due to congestion. In agreement with these results, Santos et al. (2015) pointed out that the internalisation of externalities is not always an advantages, especially as far as shipments over short or medium distances are concerned, because pre and post road haulage has a great effect on the price of transport. Some of the negative externalities for freight transport are shown in Fig. 10. In this thesis only air pollution, noise pollution and greenhouse gases emissions are included due to the unreliability or uncertainty in the case of accidents and congestion.

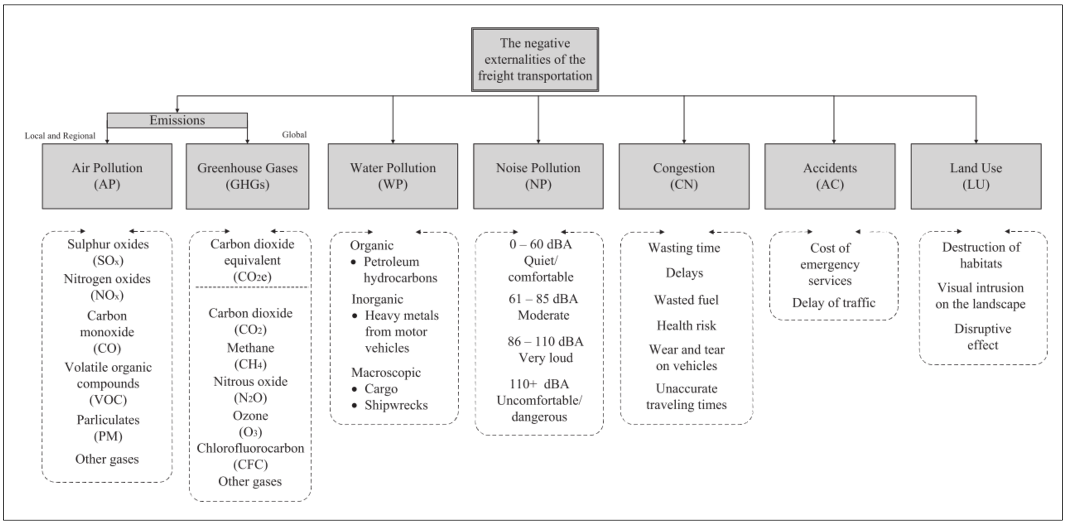


Fig. 10 The classification of some negative externalities of freight transport (Demir et al., 2015)

2.2.3 Cost calculation

In this section an analytical application of proposed linear formulations has been presented for a comparison between the costs of road-rail combined transport and full road transport. Then the results were processed with the MATLAB tool in order to ensure flexibility and simplicity, in consideration of the analysis of future implementations.

The costs that are described and calculated hereafter refer to two main reference scales, namely: distance and volume (ITUs).

The door-to-door transport is hypothesised starting from origin point A to destination in point B covering a distance of 1500 km. The distance between the origin and the nearest inland terminal was assumed, for computational reasons, to be the same as that between the second terminal and the destination, whose value was varied in the different scenarios. The distances covered by rail and only by road were considered to be equal, even though this is not always the case; the error became marginal when dealing with long door-to-door distances. The input data, which were obtained from the literature, were classified as internal and external parameters, as well as being, or not being, a function of the distance. The average values displayed in Table 1 refer to the transport of a standard ITU (40' or FEU[6]). As for the externalities, it was decided to disregard accidents and congestion because of the unreliability or - at least – the level of uncertainty of the available data; the reference scales are not easily or accurately usable in a direct comparison.

[6] Forty-foot equivalent unit

Table 1 Typical internal and external costs for freight transport (ITU 40') (adapted from (Black et al., 2003))

Cost item		*Cost*	
Internal costs			
c_{road}	Road	0,98	€/km
c_h	Pre/post road haulage	2,51	€/km
c_{rl}	Rail	0,91	€/km
c_t	Terminal operation	48	€/ITU
External costs			
c_{rp}	Road pollution	0,16	€/km
c_{rlp}	Rail pollution	0,015	€/km
c_{tp}	Transhipment pollution	0,113	€/km
c_{rn}	Road noise	0,245	€/km
c_{rln}	Rail noise	0,175	€/km
c_{rw}	Road global warming	0,046	€/km
c_{rlw}	Rail global warming	0,01	€/ITU/km
c_{tw}	Transhipment global warming	0,083	€/movement

As far as transhipment is concerned, operations within the terminals were used as a summary value for the transport unit, which inherently involves movements, operations boundary, railway manoeuvres and internal checks, as well as the average time that the truck spends inside the terminal. In this phase of the study, single cost items of the terminal activities were not investigated in detail because of the great uncertainty of the related variables.

By varying the length of the drayage, from 0 to 120 km, different scenarios were created. The analytical approach was aimed at correlating the costs with the distances (d) by separating the internal ones from the external ones.

The cost calculation for the *road-only* alternative was articulated as follows:

$$C_{road} = c_{road}d + (c_{r_p} + c_{r_n} + c_{r_w})d \quad (1)$$

The final cost for the *ferroutage* called for a more complex formulation, because another variable had to be introduced, namely the location of the inland terminals ($d_{terminal}$). The cost composition for a single component of a combined transport chain is visible in the following list of formulas; this underlines that the result would be a function of the progressive distance:

- pre- road haulage

$$C_{ct\_r1} = c_h d + (c_{r_p} + c_{r_n} + c_{r_w})d \quad (2)$$

- terminal 1

$$C_{ct\_t} = c_h d + c_t + \left(c_{r_p} + c_{r_n} + c_{r_w}\right) d + \left(c_{t_p} + c_{t_w}\right) \quad (3)$$

- rail main haulage

$$C_{ct\_rl} = C_{ct\_t} + c_{rl}(d - d_{terminal}) + \left(c_{rl_p} + c_{rl_n} + c_{rl_w}\right)(d - d_{terminal}) \quad (4)$$

- terminal 2

$$C_{ct\_t2} = C_{ct\_rl} + c_t + \left(c_{t_p} + c_{t_w}\right) \quad (5)$$

- post road haulage

$$C_{ct_{rf}} = C_{ct_{t2}} + c_h(d - d_{terminal2}) + (c_{r_p} + c_{r_n} + c_{r_w})(d - d_{terminal2}) \quad (6)$$

The length of a train can obviously influences the final cost of train traction. In many countries in Europe and around the world, trains made up of approx. 20 freight cars, for an overall load of roughly 60 TEU's, are standard practice; in other countries, the figures rise to 35 wagons, or even more (Australia, Russia, the United States, albeit on generally flat landscapes). According to the European Technical specification the train length for freight traffic is between 740 m and 1050 m (The European Commision, 2014). The lengthening of the train, which can be obtained, if required, by the composition of several shorter convoys or through distributed-power freight ones (which do not exist so far), would allow a greater production of tons per kilometre per driver, if the train were fully loaded, thus reducing the unit cost per load unit (Dalla Chiara & Pellicelli, 2011).

The function obtained for rail-road combined transport costs is obviously discontinuous due to the presence of terminals and their costs items independent of covered distance.

Fig. 11 presents four examples of total costs comparison: the balance point between the two options is shifted towards greater distances when the pre- and post-haulage increase.

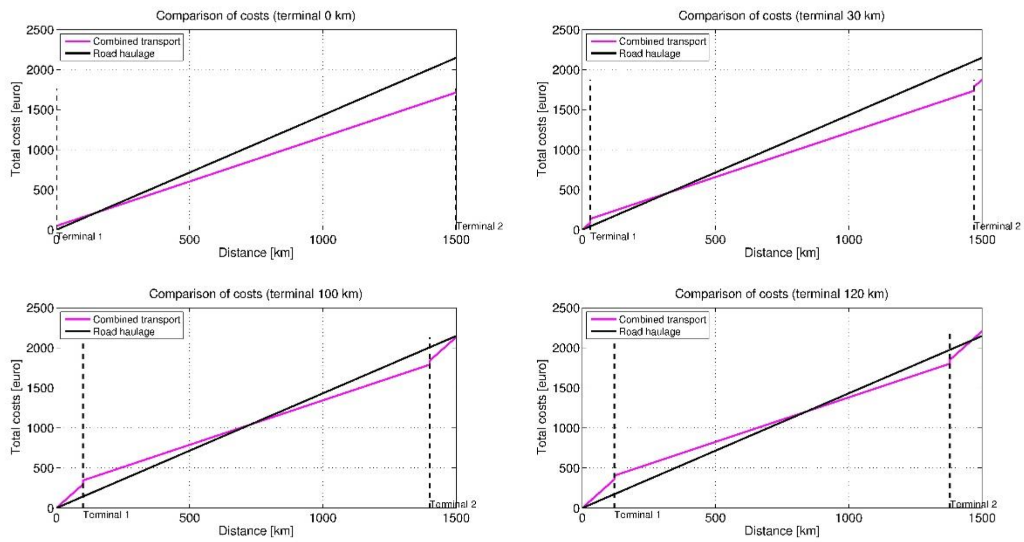


Fig. 11 Comparison of the total costs for freight transport as a function of the terminal location (related to the transport of one standard ITU 40′) (Carboni & Dalla Chiara, 2018)

Focusing on the average drayage distance of 40 km, the rail road combined transport can be cost-effective vs. the full-road mode when the door-to-door distance was approx. 400 km. This value is comparable with those mentioned in the scientific literature and with the typical European range presented in Fig. 12. The trend shows that the combined transport alternative is preferred for door-to-door distances greater than 300 km especially in the last years and even greater than 900 km in 2017. The recent report by BSL Transportation Consultants & Uic Intermodal

Union of Railways (2019) on combined transport in Europe stated similar results: the average distance of the rail leg amount to less than 400 km while the typical road distance adds up to about 50 km.

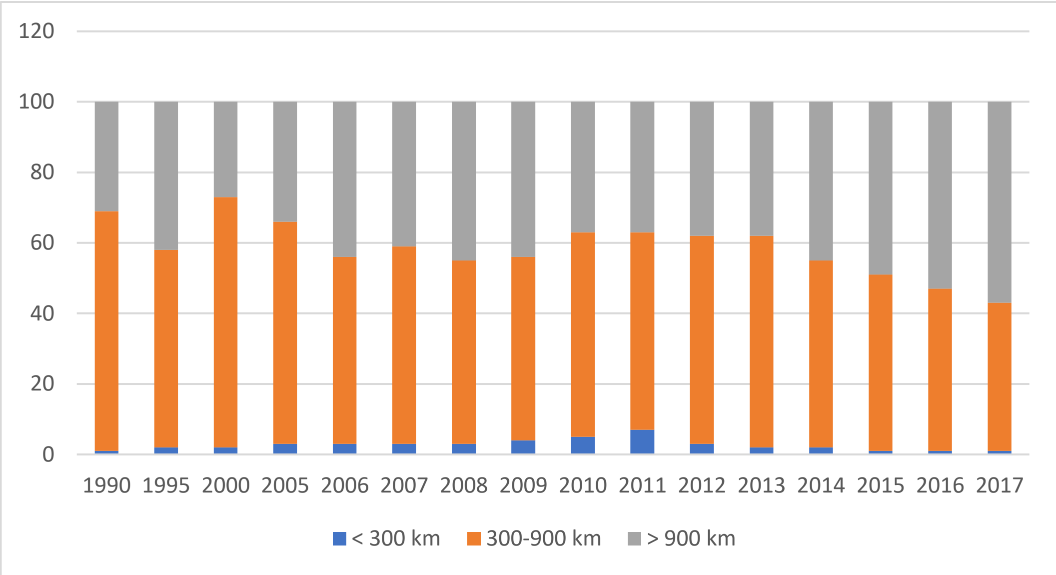
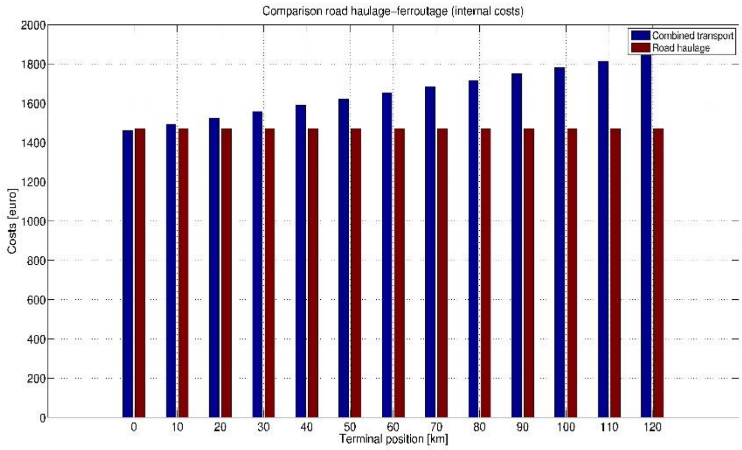
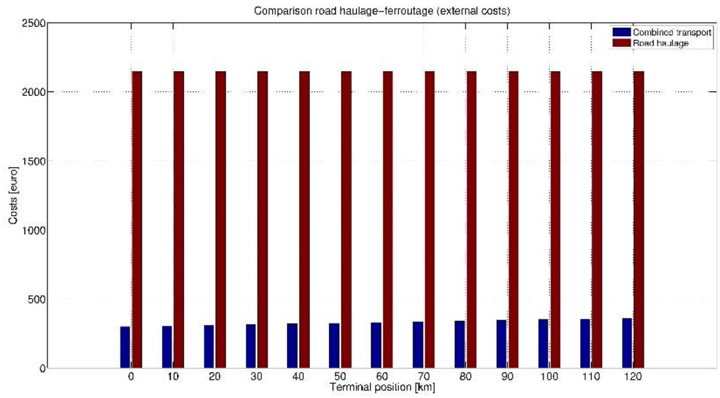


Fig. 12 The choice of combined transport mode for different door to door distances (elaboration from European Commission, 2018)

In Fig. 13 the results from several scenarios based on the hypothesized realistic input data are incorporated. The rail-road transport is competitive, compared with the full-road alternative, considering all the costs, up to distances to link the initial or final shipment points and the destinations with the chosen terminals of about 100 km or less. The external costs, as expected, make combined transport competitive since, if only the internal costs were considered, the economic advantage obtained by using the rail mode for the main distance would not be enough to offset the costs of the transhipment operations, or the higher costs for the initial and final road traction.



(a)



(b)

Fig. 13 Comparison between rail-road combined transport and full road of internal (a) and external (b) costs, by varying terminals position.

Finally, the previous formulas were implemented by changing the distance between the origin and the destination, in particular for transport over lengths of 1000, 1500, 2000 and 2500 km (Fig. 14). A certain aspect that emerges has not yet been sufficiently highlighted in the relevant literature: the shift towards the right of the balance point between the cost of the unimodal road transport and that of rail-road combined transport means that, over long distances, combined transport can be economically competitive, even when the drayage covers greater distances.

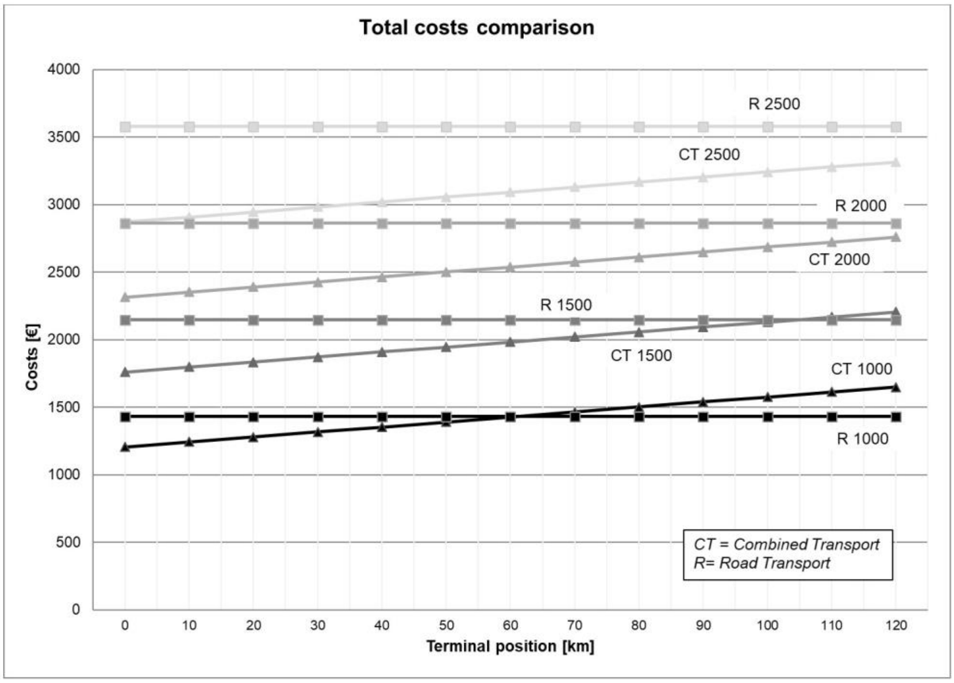


Fig. 14 Comparison of the total costs for changes in the origin-destination distance (related to the transport of one standard ITU 40') (Carboni & Dalla Chiara, 2018)

In conclusion, the results from the different scenarios elaboration confirms and contributes with further details what presented in literature, as the effect of external costs is lower if the pre- and post- haulage is too long due to the negative externalities of road solution which play a greater role. The location of inland terminals and therefore the drayage length have a heavy impact on the final costs. Rail-road transport may be competitive if the external costs are internalised and if the total distances are sufficient to exploit the advantages of rail transport. Moreover, rail-road combined transport over longer door-to-door distances (approx. 2000 km) may be cost-effective, even for a high drayage length. In the case of short door-to-door distance, the terminal operations costs to transfer the unit from one mode to another one can limit the competitiveness of intermodal transport. In fact, if the railway haulage is too short, the economic benefit of the intermodal alternative is overpowered by the terminal costs and the pre/post road haulage. The role of intermodal terminal is very important, and it is the focus of the second part of this thesis.

2.2.4 Technical considerations

The general strategy to introduce a more sustainable freight transport is to intercept the traffic where these are by their nature intermodal and typically have the maximum shares of goods traffic obtainable on the market: the port terminals. Likewise, a series of goods should be attracted also by rail as perishable goods, for example.

The considerations reported in previous section may not be suitable in some cases, such as in the case of a short distance (as explain in section 2.2.5) covered by a shuttle train: scheduled and fixed composition, large quantities of goods with the same path. In fact, this type of service requires lower times and costs for terminal operations and the reduction or elimination of pre- haulage, which have less influence on rail competitiveness. The topicality of the theme, at a national Italian level, is also highlighted by the current “Piano Strategico Nazionale della Portualità e della Logistica”, where the importance of the development of dry ports is highlighted.

Nevertheless, the modal shift to combined transport should be also encouraged by innovations in rolling stock that could allow market share gains not currently transportable by rail. For instance, one innovation could be the use of multiple-traction long freight trains (35 wagons/750 m), with distributed power, if possible with electrification on single wagons, in order to ensure also the transport of controlled temperature goods and with electrical control for pneumatic braking on every wagon (Fig. 15). This improvement allows also for tele diagnostics, improving for example the maintenance of electrical, mechanical and pneumatic sub-systems and the cargo supervision.

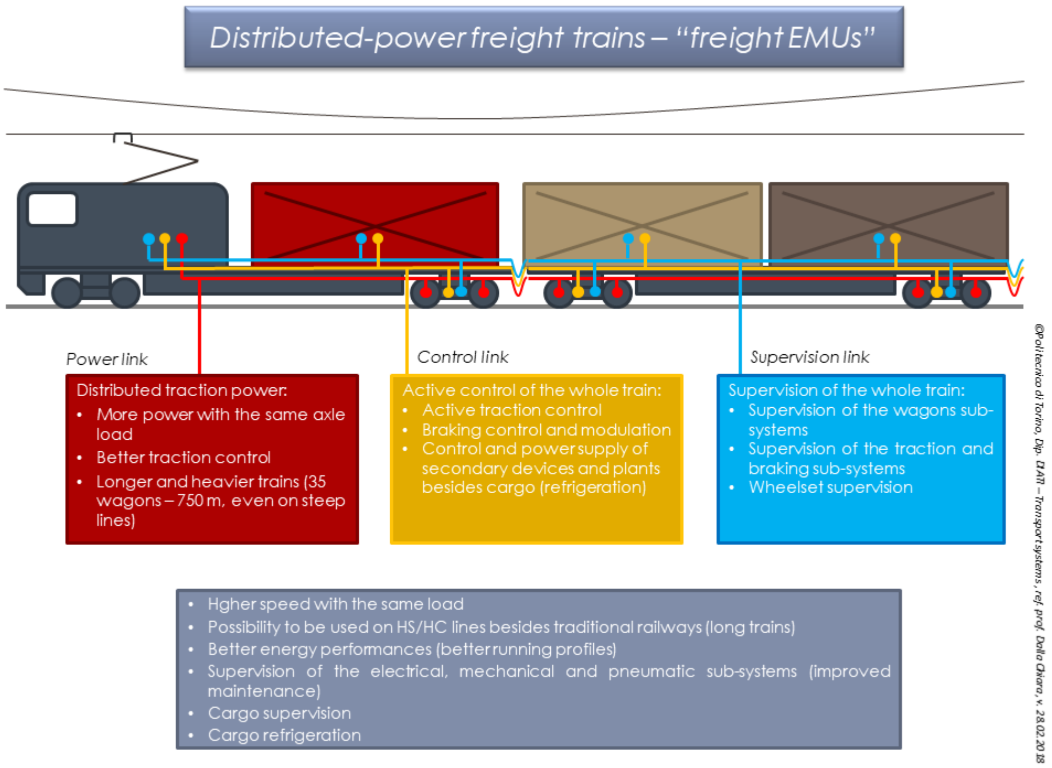


Fig. 15 Main characteristics of innovative train: distributed-power freight trains (Dalla Chiara & Carboni, 2018)

A modern freight train could use the HS/HC lines besides traditional railways but to share the infrastructure set up for high speed with passenger trains, must have specific technical requirements that allow it, for example, to cover even the portions of traditional lines, for connections with the marshalling stations and the intermodal terminals, which are fundamental nodes of the network and indispensable for the service. This requirement can be translated into multi-current and multi-voltage locomotives, equipped with signaling systems compatible with the equipment of the HS lines, i.e. ERTMS / ETCS level 2. It is therefore desirable that freight trains increase their performance, as the “freight EMUs” train proposed in Fig. 15, to increase its market share. For example, a modern "high-speed freight train" could guarantee rapid and reliable transport attractive for the e-commerce sector, which probably would be able to respect the length and weight characteristics required, since they are generally parcels of medium-weight.

Rail's share in the freight land transport market in Europe dropped from 32.6% in 1970[7] to 17,4% in 2016[8]. Perhaps the kinds of goods carried out by railways are different, in the past the railway mode are used for large masses, weights and considerable dimensions which today probably choose the road.

In Italy for example, in 1970 the freight transport by rail was around 55.357.000 ton that come down only five years later to 42.666.000 ton reaching a historical minimum (Ferrovie.info, 2018). This was due above all to the growth of the highway system and the spread of road transport, which were encouraged to the detriment of railway. The main goods categories were: agricultural products (and live animals), foodstuffs, solid mineral fuels, oil products, ores and waste metallurgical, metallurgic products, construction materials, fertilisers, chemicals, machine and vehicles and others. The trends of these type of goods are shown in Fig. 16, besides the category "machine, vehicles and others", all the other products present a decrease from 1970 to 1985. The amount of goods carried out by railway in 2015 in Italy are reported in Fig. 17, the products categories[9] are quite different from previous graph and also relative quantities.

[7] From (Directorate-General for Energy and Transport, 2008).
[8] From (European Commission, 2018).
[9] Regulation (EU) No 70/2012

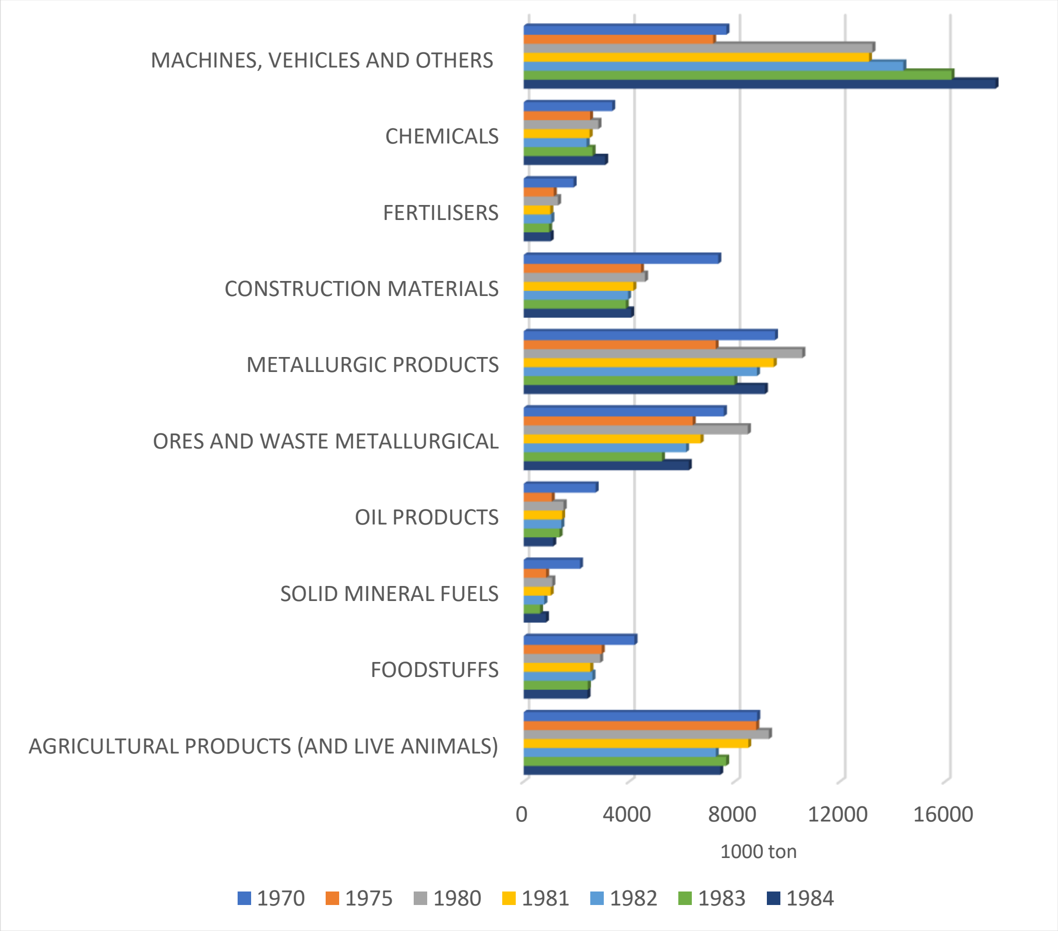


Fig. 16 Trends in the rail transport of goods for third parties in Italy by product (elaboration from (Ferrovie.info, 2018)**).**

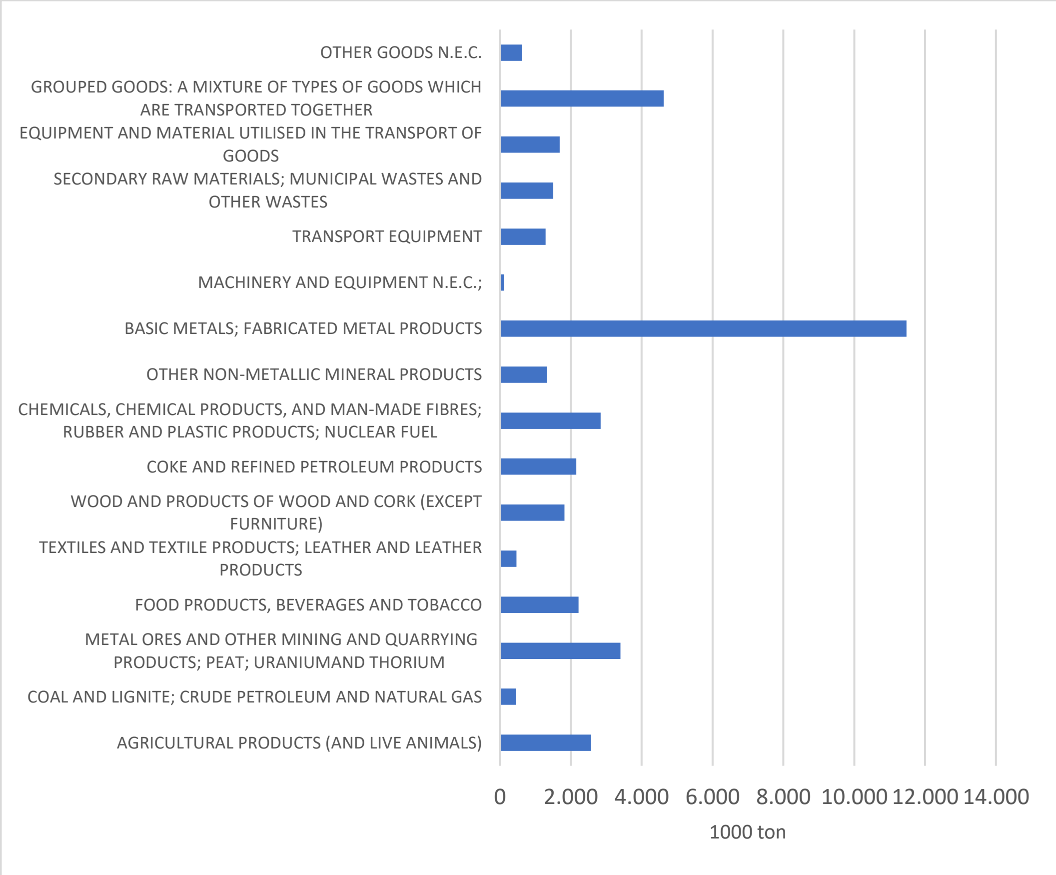


Fig. 17 Rail transport of goods in Italy by product in 2015. Unidentifiable goods are 41.365.00 ton (data source: Istat)

The comparison of types of goods carried out by rail in 1970-80 (Fig. 16) and in 2015 (Fig. 17) are shown in Fig. 18, in order to make a comparison, because over the years the product categories have changed, we have focused on some better comparable ones, in particular agricultural products and foodstuffs have lost their market share. Whereas the total amount of goods moved by road in 2017 in Italy is reported in Fig. 19 divided by product category and distance travelled.

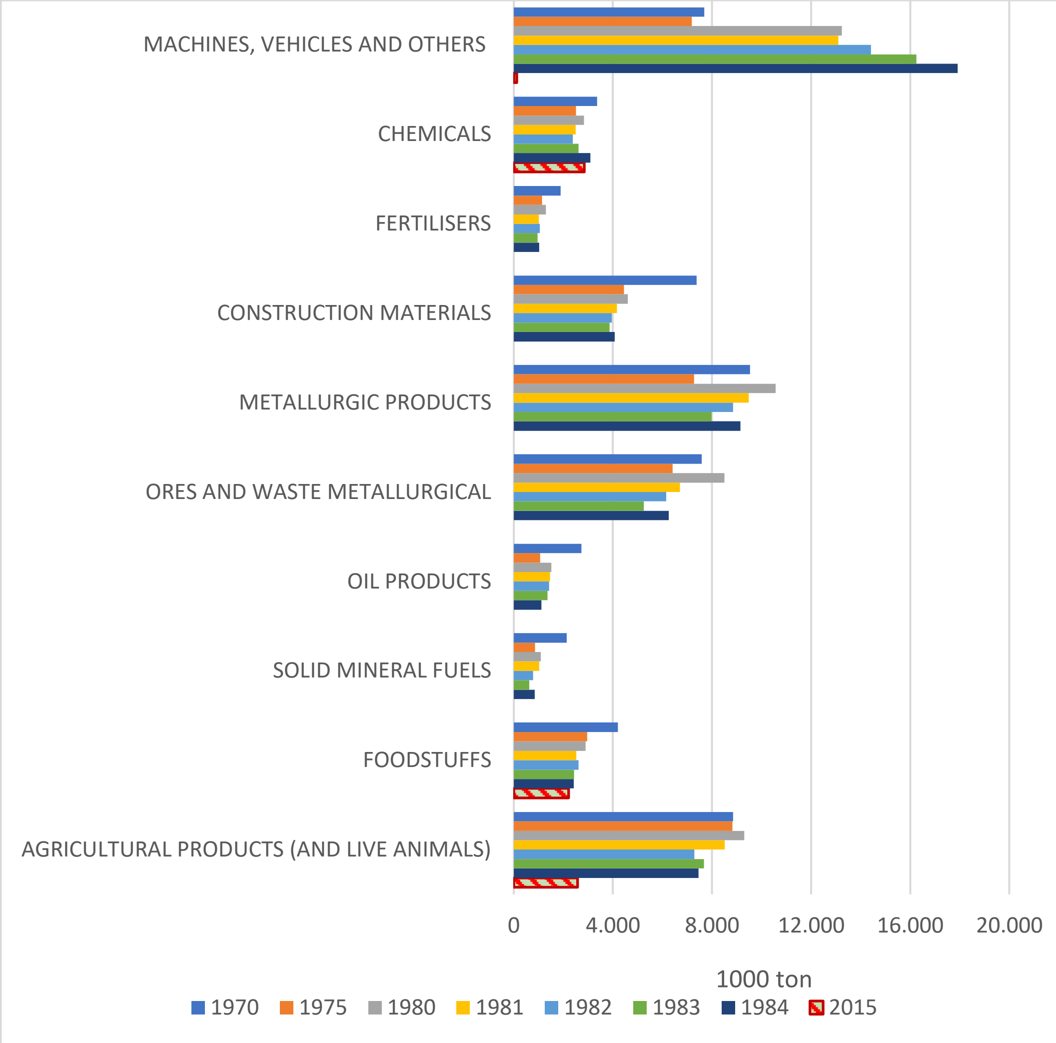


Fig. 18 Trends in the rail transport of goods in Italy by product in different years (data source: Istat and (Ferrovie.info, 2018)**).**

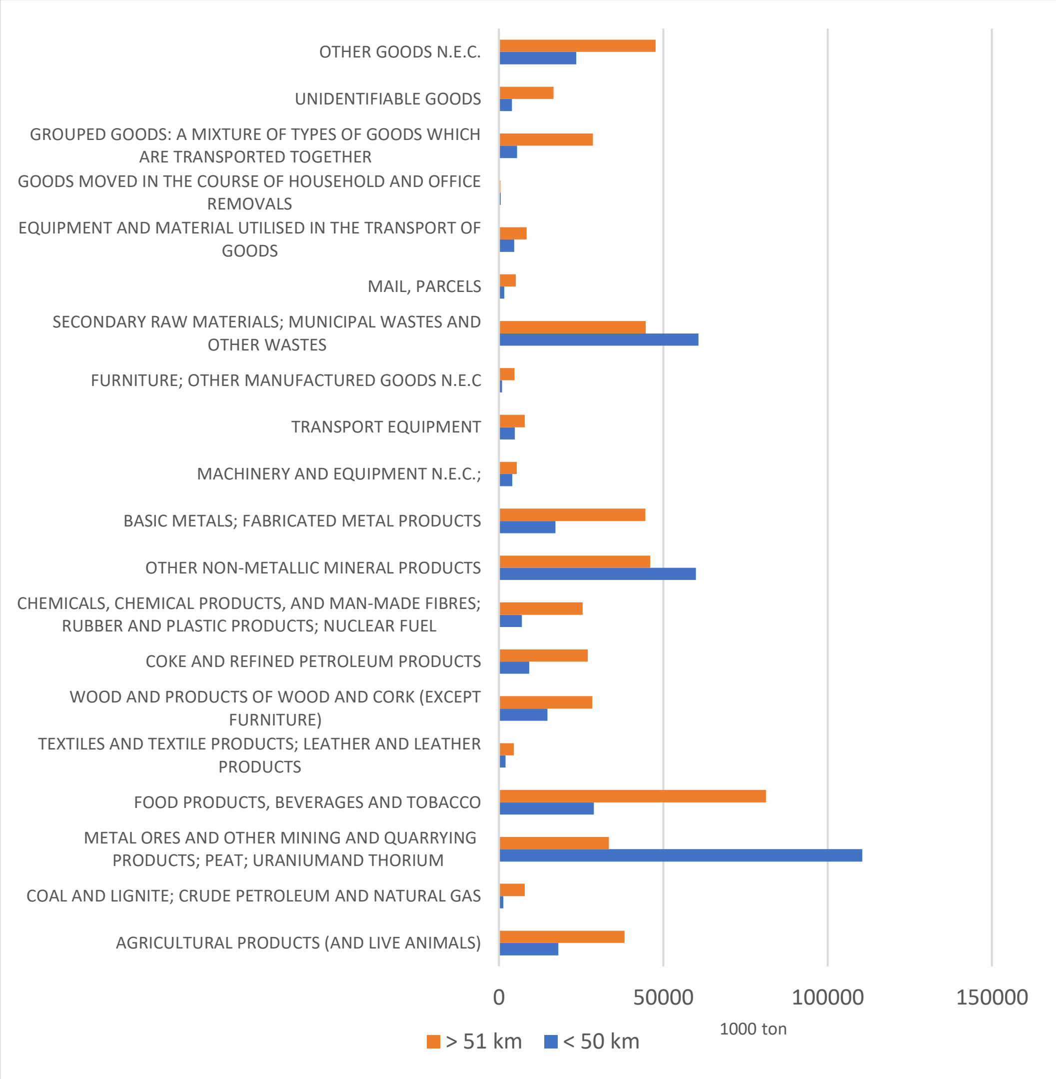


Fig. 19 Road transport of goods in Italy by product in 2017 and its distance covered (data source: Istat)

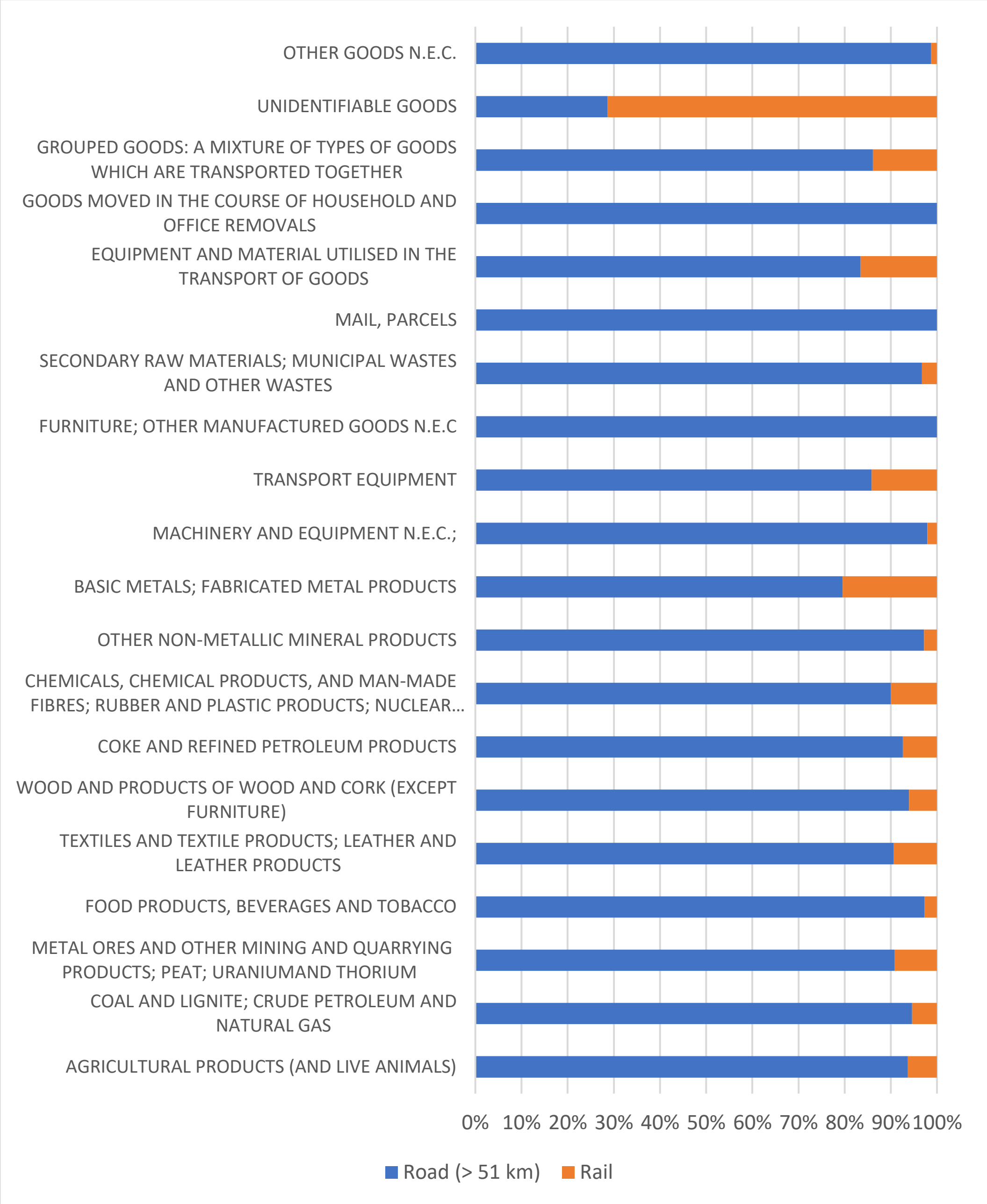


Fig. 20 Modal shares by product category in Italy in 2017 (data source: Istat)

In Fig. 20 the modal share by product category is reported considering the goods moved by road only in the case of distance covered greater than 50 kilometres. Thanks to the technical improvement desirable for rolling stock previously described, some modal share of railway mode can be increased by subtracting heavy-duty vehicle traffic which would result in both a reduction in externalities for the society and an improvement in the performance of the road freight transport itself which would benefit from less congestion. The food and agricultural category for instance could also be transported by rail with innovative trains described above that allow temperature control. A train with distributed power allows also for tele diagnostics improving the cargo supervision, so special product categories as wastes and chemicals may be carried on with greater guarantees of safety, increasing the modal share of railways. Finally, also the category of mail and parcels, category with a very high demand thanks to the development of e-commerce, can be attracted by an express train service that guarantees large volumes (HS/HC lines).

Trains with greater length and weight could increase the competitiveness of railway mode and therefore intermodal transport, provided that the infrastructure is also innovated to accommodate trains with these characteristics. This means that, for instance, the minimum braking and stopping distances must be guaranteed and the locomotives (or the locomotive) are able to provide sufficient traction effort.

To conclude, the operational market share of combined transport could be extended to weak sectors which would not be able to produce sufficient traffic for a direct train. The intermodal terminal should overcome this inconvenience implementing the gateway function instead of sorting complete wagons through the marshalling yards. The gateway function is a modality of managing the railway traffic which is accompanied by a more intensive use of the terminals for the direct sorting of the ITU's between trains (Dalla Chiara & Pellicelli, 2011). In addition, what was once widespread traffic using the railway mode, and the marshalling yards for sorting, can become intermodal traffic if the rolling stock allows it and if the terminals also provide a gateway function.

2.2.5 Dry-port and seaport connection

A shuttle freight train service is typically characterised by a scheduled and fixed composition of convoys as well as fixed path allocations. The usually covered distances are short, compared to the traditional rail ones, and as has emerged from previous analysis. However, this alternative is being adopted successfully, especially for port (or seaport) and back-port (or dry port[10]) connections. In fact, the phenomenon of increasing ship capacity can lead to a port infrastructure crisis, and the role of back-ports (terminals or logistic platforms near ports) is becoming significant. Functional seaport inland access is important for the efficiency of the transportation chain if the maritime containerised transport continues to increase (Roso, 2007).

[10] Dry ports are defined as inland freight terminals that are connected directly to one or more seaports with high-capacity transport means, where customers can drop off and pick up their standardised units as if they were at a seaport (Crainic et al., 2015).

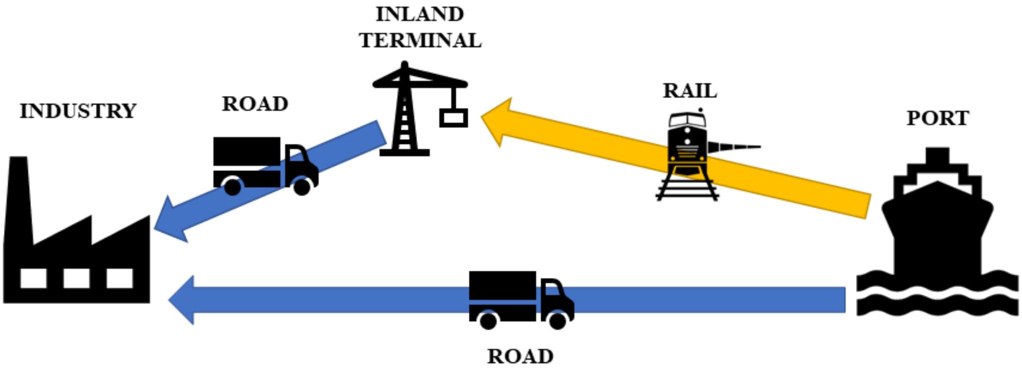


Fig. 21 Schematic representation of possible port-inland connections.

These routes are often covered by road transport, because ports do not always have good and efficient railway connections (Fig. 21). In terms of productivity and efficiency, a shuttle service can be a convenient choice. In fact, trains with a fixed composition lead to lower costs and less time for terminal operations. Since there is no pre-haulage by road, the intermodal transport chain increases its competitiveness compared to "all-road" transport because the break-even distance discussed in section 2.2.3 decreases as shown in Fig. 22. In addition, a good and controlled rail connection between port and inland terminal could streamline the port and customs practices of the units that could take place directly in the terminal in order to free spaces in the ports. Services such as storage, consolidation, depot, maintenance of containers, track and trace, customs clearance, etc. should be available at the dry port, which extends the gates of the seaport inland, with shippers viewing the dry port as an interface to the seaport and shipping lines (Roso, 2007).

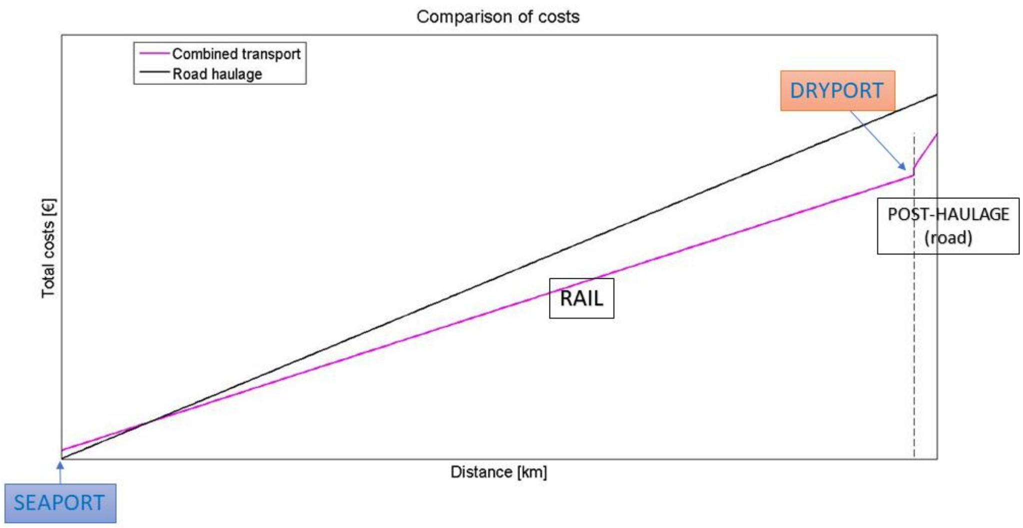


Fig. 22 Costs trend for seaport-dry port connection

It is also important to consider the digital tachograph obligation, with the associated rest times for drivers, as one of the main limitations of road transport. In short, according to the EU rules on driving hours, a truck driver must not drive more than:

- 9 hours a day - this can be extended to 10 hours twice a week;
- 56 hours a week;
- 90 hours in any 2 consecutive weeks.

To sum up, the dry-port and sea port connections by railway could be a competitive solution for several reasons including:

- the train composition is fixed this means that the load remains unchanged until the end of the journey without the need for decomposition and composition operations; as well as the composition of the wagons can remain the same, reducing the costs and times of terminal operations.
- Services such as storage, consolidation, depot, maintenance of containers, track and trace, customs clearance should be available at the dry port to reduce the trucks queue and free up space in the port docks for instance.
- The dry-port operations should be efficient to meet the needs of the transport service, it should have well-organized access to the port and a good interface with the road, guaranteeing a scheduled and reliable high-capacity transport.
- The train service must guarantee safe, controlled, fast and reliable connection.
- The maritime containerised transport continues to increase and often the port capacity and related competitiveness on the market could be overstretched. In this framework, a frequent rail service towards the hinterland could be a solution to move the high number of containers more quickly.
- The number of containers transported on a train would require a corresponding number of road vehicles and this would hardly meet the European demands for environmental sustainability, without counting the costs and constraints of the tachograph.
- A good dry-port and sea port connection should be accompanied by a digitalisation of the process, guaranteeing the correct communication between the actors and the units traceability.

Venice Marghera - Padua is an example of a seaport and dry port connection, and it is also important in the framework of TEN-T Corridor (section 1.2). This link in fact is involved in two corridors: Baltic-Adriatic corridor and Mediterranean corridor.

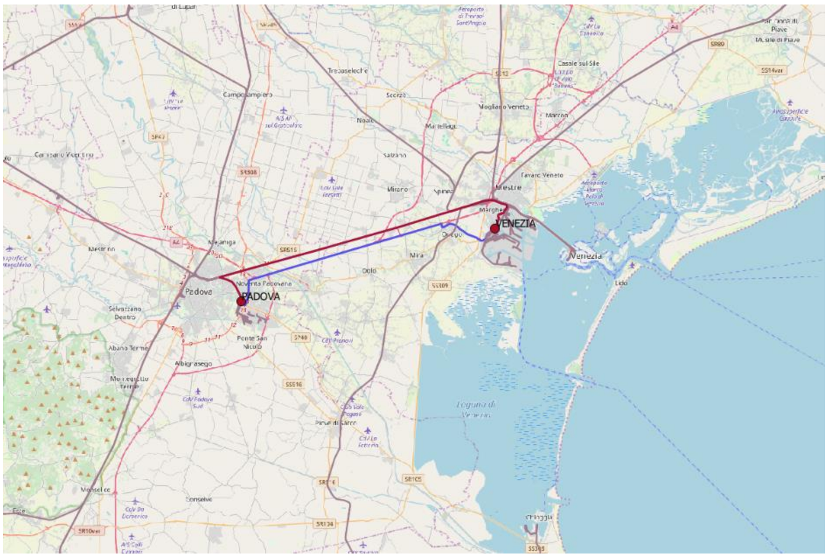


Fig. 23 Venice Marghera – Padua possible connections (red line=train; blue line= road)

The distance covered by trucks is approx. 32 km, whereas the length of the railway is approx. 34 km, so Padua can be considered as a close dry port according to Table 2. Hypothetically, the speeds could be chosen as 90 km/h for trains and 60 km/h for trucks. The largest cargo ship, after the recent adjustment, that can be accommodated in the Venice Marghera Port has a capacity of 8500 TEU, thus if 40’ containers were considered, the total amount of ITUs would be 4250; it was assumed that the destination of the 40% of these containers is Padua Interporto (the final destination of ITU is not considered due to the focus on dry-port and seaport connection). Through a simplified calculation it is possible to compare a train shuttle (approx. 20 ITUs per train) and a truck fleet service.

Table 2 Dry port classification (elaboration from Crainic et al., 2015)

Configuration	Distance from the seaport	Main function
Close dry port	< 50 km	Satellite Terminal
Midrange dry port	≥ 50 km, ≤ 500 km	Load Center
Distant dry port	> 500 km	Transhipment

It was assumed, for the cycle time calculation, that the terminal operations needed 1 hour per truck and 2.5 hours per train (Carboni & Dalla Chiara, 2018). The cycle time was calculated as almost 3 h, in the case of a truck, and 6 h for a train. Therefore, one truck and one train can carry out respectively three roundtrips and two roundtrips according to the driving constrains and assuming a certain degree of occupation of the route (Fig. 24). One truck can obviously carry just 1 ITU, while a train can carry at least 20 ITUs. Thus, without considering what happens on the return journey, trucks can carry out 3 ITUs per day, while a train shuttle can perform 40 ITUs.

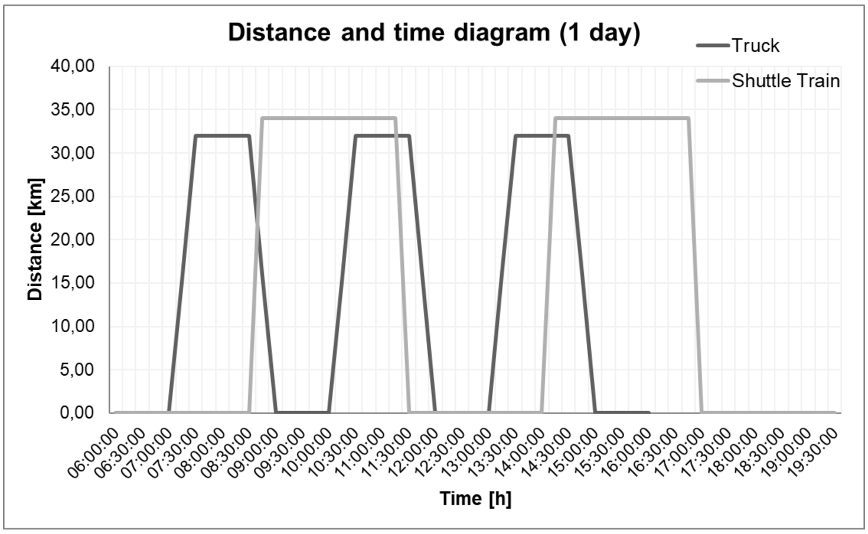


Fig. 24 Diagram of an example of a truck service and a shuttle train service in a day

It is possible to hypothesise 2 shuttle trains per day but neglecting the terminal capacity and the availability of the train paths, for a total of 80 ITUs to the Padua Interporto per day. At least 22 days of train shuttle service would be required to deliver 1700 ITUs. To ensure deliveries in the same time, the truck fleet would need to be composed of 36 drivers operating five days per week. It is easy to see that the second solution is less convenient, in terms of economics, efficiency and environment (Fig. 25).

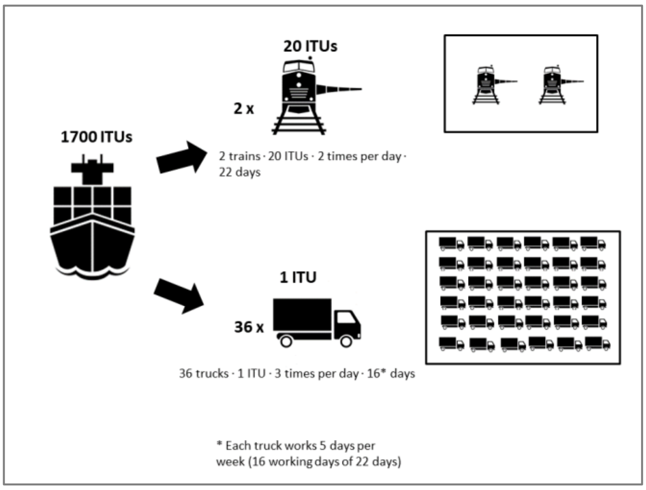


Fig. 25 Comparison of a shuttle train service and a truck fleet service carrying containers from a port to a back port in 22 days.

In Table 3 the comparison of shuttle train service and truck fleet one to connect Venice Port and Padua is summarized.

In general, with dry port implementation seaport’s congestion from numerous lorries is avoided and roads congestion, accidents, road maintenance costs and local pollution are reduced as well.

The convenience of the rail mode can also emerge for short distances, but in the case of specific services, such as a shuttle train, with scheduled and fixed compositions and large quantities of goods with the same path, which require lower times and costs for terminal operations. The dry port concept goes beyond the conventional use of rail shuttles for connecting a seaport with its hinterland due to the concept of extended gate previously mentioned (Roso, Woxenius, & Lumsden, 2009). The advantages are related to the modal shift from road to rail that results in a reduction of congestion at the gates of the port and its surroundings and reduce the externalities along the route.

Table 3 Comparison of a shuttle train service and a truck fleet service from Venice Port and Padua.

Venice-Padua	*DISTANCE*	*SPEED*	*ITUs*	*TERMINAL OPERATIONS*	*CYCLE TIME*	*TOUR PER DAY*	*tot ITUs*	*n. VEH*	*DAY*
	km	*km/h*	*#*	*h*	*h*	*#*	*#*	*#*	*#*
ROAD	32	60	1	1	3	3	3	36	16
RAIL	34	90	20	2,5	6	2	40	2	22

2.2.6 Energy analysis

The energy analysis in intermodal transport for freight regards principally the following aspects (Zumerchik et al., 2011):

- Line Haul Energy is the fuel/energy needed to transport goods from origin to destination through different modes.
- Modal Transfer Energy is the fuel/energy used in the terminal for modal transfer by cranes, drayage trucks, yard tractors, service vehicles, as well as energy use for switching.
- Storage Energy refers to deposits and storing.

The second aspect will be discussed below in the context of terminal simulation (section 3.4.2). The third one is will not be dealt with in this thesis.

As regards the Line Haul Energy, Pinto et al. (2018) have showed that intermodal road-rail operations would reduce emissions by up to 77.4%, be up to 43.48% more fuel-efficient and up to 80% cheaper than operating solely with road transport, posing as a viable strategy to enable more companies and countries to mitigate climate change.

Other considerations about energy consumption and related emissions in rail-road combined transport can regards the last mile covered by road (better described in section 2.3), which is relevant parts, as pointed out in the previous sections, also in terms of internal and external costs.

A possible solution to improve the efficiency of road drayage could be alternative power supply. A number of manufacturers are currently proposing new solutions for the power supply of trucks, such as electric vehicles for lower classes of weight (up to roughly 5-7.5 tons), hybrid vehicles and CNG or LNG engines for higher weights. These alternatives, in particular the hybrid or electric ones, are usually compatible with the distances covered during pre- and post-haulage, considering the location of charging stations in the terminals. The positive effects of replacing traditional engines are mainly reflected on the external costs, due to the reduction in emissions, and on the internal costs, in terms of consumption

(Carboni & Dalla Chiara, 2018). Decarbonizing heavy-duty vehicle activity by transitioning to zero-emission vehicle technologies, including electricity and hydrogen technologies, presents an huge challenge as stated by Moultak, Lutsey, & Hall (2017). They compared three technologies for zero-emission heavy-duty freight vehicles: electric plug-in, electric catenary or in-road charging and hydrogen fuel cell. They found that electric and hydrogen fuel cell vehicles would cost 25%-30% and 5%-30%, respectively, less than diesel vehicles. Another outcome of their work is that the hydrogen fuel cell might be a key element for long distances, while plug-in electric vans may be useful to cover shorter distances. Fig. 26 shows the hypothetical contribution of the introduction of alternative fuels for pre- and post-haulage with respect to traditional one: this improvement is considered with a reduction of 20% for road costs compared with Table 1, which is a realistic percentage according to recent data in the literature. Thus, the qualitative results reveal that the equilibrium point between the two alternatives moves to the left, this means that the combined solution become more competitive as predictable.

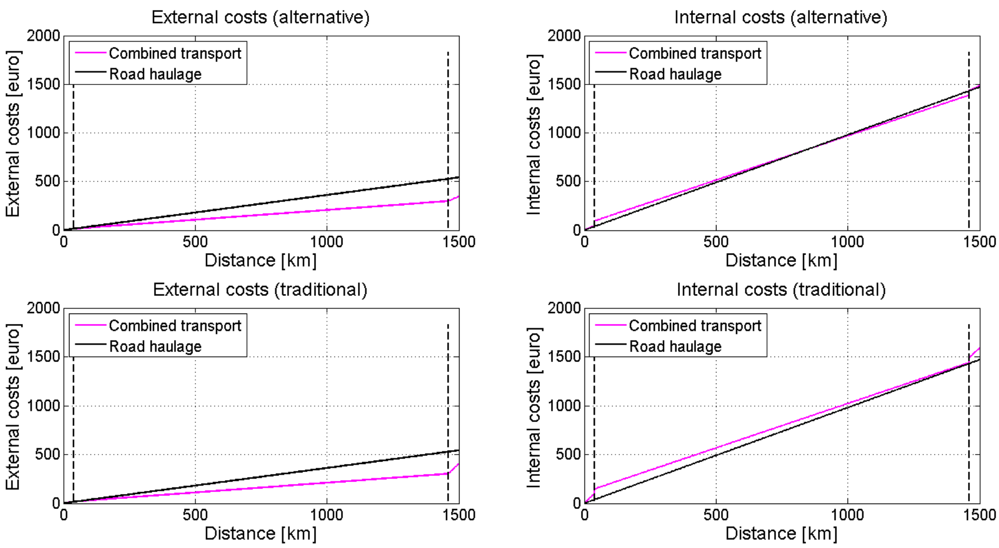


Fig. 26 Comparison of the external and internal costs for the two alternatives using an electric solution for drayage (alternativo scenario) and a traditional one. (terminal location: 40 km) (transport of one standard ITU 40').

Different applications of alternative solution for road transport be defined due to their specific characteristics, for example the electric plug-in is preferable for light urban vans or medium-duty trucks for regional transport, so compatible with the pre/post- haulage for combined transport (see also section 2.3). While hydrogen fuel cell and LNG guarantee more power and autonomy also for long-haulage operations. Always on long distances, the recent "e-highway" projects and the platooning solutions should be considered. The electrified highways would guarantee the use of hybrid heavy-duty vehicles for freight transport by road to reduce the environmental impacts. Obviously, this solution required high infrastructure costs and the impacts on traditional traffic flow as well as the operation costs should be evaluated. The second modern solution for road freight transport could be the truck platooning which comprises trucks equipped with driving support systems one closely following the other; in the future of autonomous driving the whole could happen without drivers or with truck driver only for the leader. This solution, often studied and tested, can offer several benefits such as the reduction of consumption and emissions due to the decrease of aerodynamic load on individual vehicles. In addition, the externalities for the society decreased: less accidents thanks to the driving assistant systems and less congestion of roads due to the close running of consecutive vehicles. Finally, the transport companies can enjoy important benefits: alternating drivers can reduce stops for mandatory rest periods, reducing overall travel time and making better use of vehicles (Mauro, Dalla Chiara, Deflorio, Carboni, & Cossu, 2017) (Tsugawa, Jeschke, & Shladover, 2016).

2.2.7 Modal split model

In the previous sections the competitiveness of rail-road combined transport is studied based on its main technical and economic characteristics. In the field of transport modelling the concept of utility is introduced to represent the attractiveness of different alternatives (Ortúzar S. & Willumsen, 2011). The utility function in a random utility theory, suggested for the comparison of freight traditional road and combined transport according to (Dalla Chiara, Deflorio, & Spione, 2008), is composed by two main terms as shown in equation (7) where j is the alternative and i is the user.

$$U_j^i = V_j^i + \varepsilon_j^i \qquad (7)$$

V_j^i is the systematic utility and it is usually defined as a linear combination of variables (observable attributes of the alternative) and their coefficients; while ε_j^i is a random part which described an unobservable portion of the utility (measurements and observational errors, particular tastes of each individual…).

All alternatives can be chosen by users even if each user selects the alternative that maximizes his perceived utility. In equation (8) is reported the probability for each alternative (all k of the set of the alternatives for i).

$$P_j^i = prob\left[U_j^i > U_k^i\right] \qquad (8)$$

The simplest and most popular discrete choice model is the Multinomial Logit Model where for the random components Gumbel distributions are adopted. The probability to choose each alternative is:

$$P_j^i = \frac{\exp(\frac{V_j^i}{\theta})}{\sum_k \exp(\frac{V_k^i}{\theta})} \qquad (9)$$

where θ is the parameter of the Gumbel distribution (10).

$$\sigma^2 = \pi^2\theta^2/6 \qquad (10)$$

In the case proposed in this thesis two alternatives are taking into account for the freight transport, as underlined in previous sections: traditional road transport and rail-road combined transport. The alternatives present different peculiar attributes, already defined, as well as the main technical and economic parameters which can guide the user's choice. More specifically, travel time and travel costs are probably the main attribute which influenced the choice. As regards the first one, the two alternatives present characteristic aspects:

- *road-only* alternative. The travel time can be calculated assuming an average speed to cover the road distance from origin and destination. After obtaining the driving hours required, it is necessary to add the hours for stops and mandatory rest periods[11] (see 2.2.5).
- *rail-road* alternative. The travel time is composed by several time intervals related to the intermodal process addressed in detail in section 0: pre and post-haulage by road, loading and unloading operations in intermodal terminals (including also other terminal operations see section 3.1) and railways transport section.

Other crucial elements are costs treated extensively in sections 2.2.1, 2.2.2 and 2.2.3. Then, with reference to the increasingly important issue of the environmental sustainability of transport, other attributes can be included in both the utility functions as the environmental impacts and energy consumptions. In detail, the environmental impacts can be divided into global warming (CO_2 emissions), pollutant emission/concentration (CO, PM, NO_x) and noise. Finally, further attributes can be included specifically for the single alternative, as for example the frequency of the train service for the rail-road combined transport.

To conclude, the systematic utilities functions for the two alternatives, road-only (r) and rail-road combined (rr), are the following:

$$V_r = R + \beta_t T_r + \beta_c C_r + \beta_{gw} GW_r + \beta_e E_r + \beta_n N_r + \beta_{ec} EC_r \quad (11)$$

$$V_{rr} = RR + \beta_t T_{rr} + \beta_c C_{rr} + \beta_{gw} GW_{rr} + \beta_e E_{rr} + \beta_n N_{rr} + \beta_{ec} EC_{rr} \quad (12)$$

Where:

- β are the coefficient to define the relative influence of each attribute;
- T_r is the travel time by road including stops;
- T_{rr} is the total travel time for rail-road transport chain including all phase of the process;
- C_r is the total cost of road-only transport;
- C_{rr} is the total cost of rail-road combined transport;
- GW_r are the total GHG emissions for road alternative which can be expressed in gCO_2eq;
- GW_{rr} are the total GHG emissions for rail-road alternative which can be expressed in gCO_2eq;
- E_r are the total pollutant emissions, including CO, PM, NO_x, for road alternative which can be expressed in g/m^3;

[11] Regulation (EC) No 561/2006 of the European Parliament and of the Council of 15 March 2006 on the harmonisation of certain social legislation relating to road transport.

- E_{rr} are the total pollutant emissions, including CO, PM, NO_x, for rail-road alternative which can be expressed in g/m^3;
- N_r are the total noise emissions for road alternative which can be expressed in dB(A);
- N_{rr} are the total noise emissions for rail-road alternative which can be expressed in dB(A);
- EC_r are the total energy consumptions for road alternative which can be expressed in ktep;
- EC_{rr} are the total noise emissions for rail-road alternative which can be expressed in ktep;
- RR, R are the alternative specific constants which can include elements that are not easily measurable or observable.

This is an example of how the attributes first examined (times, costs and energy parameters) can be included in the utility functions for the modal choice for the freight transport. In Fig. 27 the relationships between some measures emerged in the paragraphs of this thesis and the attribute of systematic utility (equation (12)) are reported. it is important to underline some attribute (green colour in the figure)

It is important to underline that some attributes (green colour in the figure) become more and more important, linked to environmental sustainability mainly, and can be positively influenced by the elements dealt with in this thesis, such as the efficiency of the terminals and the technical improvement of rolling stock. These measures must be fundamental in a discrete choice model and can contribute to increasing the competitiveness of intermodal choice.

Nevertheless, the model calibration and the parameter estimation are out of scope of this thesis.

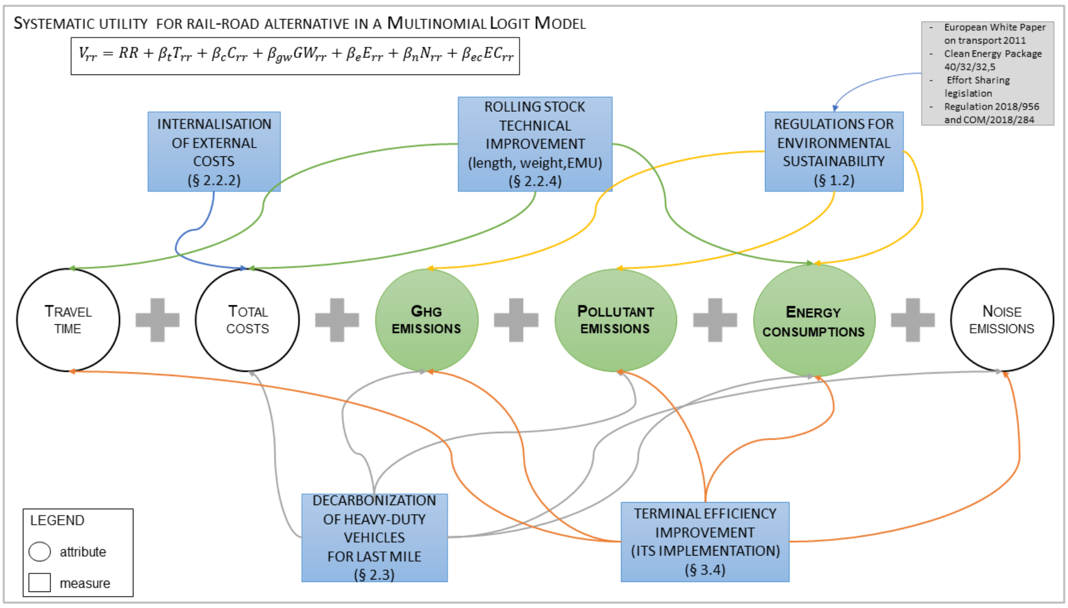


Fig. 27 Attributes of systematic utility for rail-road alternative and the measure that can influence them with reference to the sections dealt with in this thesis.

2.3 Last mile: urban freight transport

To better analyse the freight door-to-door movement, this thesis includes a focus on section of transport chain: the last mile covered by road. In cities usually affected by critical traffic conditions, high levels of urban freight activities may create additional problems in terms of congestions and environmental impacts.

The method proposed allows the calculation of city accessibility for freight distribution services using the positioning data collected during the van's trips (Floating Car Data - FCD) on classified network. "Accessibility" could be defined as the ease and extent to which road network enable deliveries vehicles fleet to reach the various zones of city.

The work presented refers to one discussed in Pirra, Carboni, & Deflorio (2018) and Pirra & Diana (2019).

The method has the potential to:

- solve the issue of hubs locations;
- better evaluate the compatibility between electric vehicles and urban trips (also considering the delivery stops);
- evaluate the role of ITS (AVL - Automatic Vehicle Location, for instance).

In relation to the last point, thanks to the positioning data collected during the van's trips (Floating Car Data - FCD) the effect of ITS also in this part of transport process was investigated.

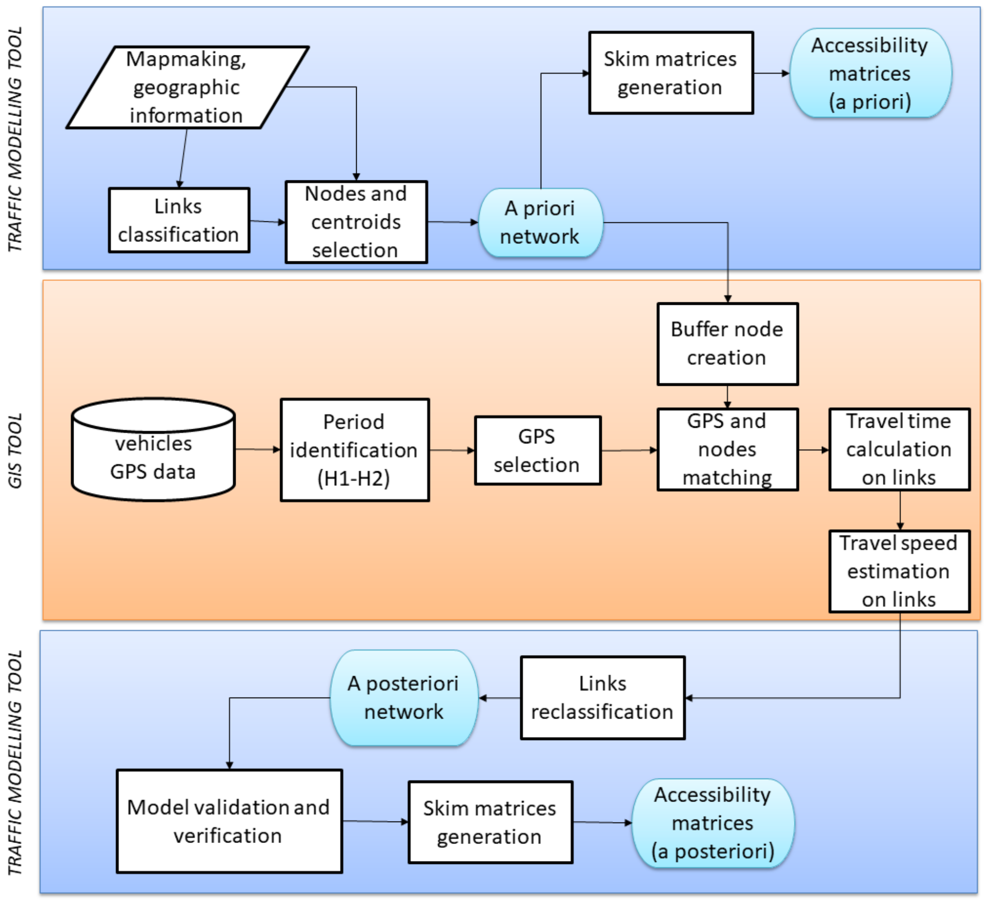
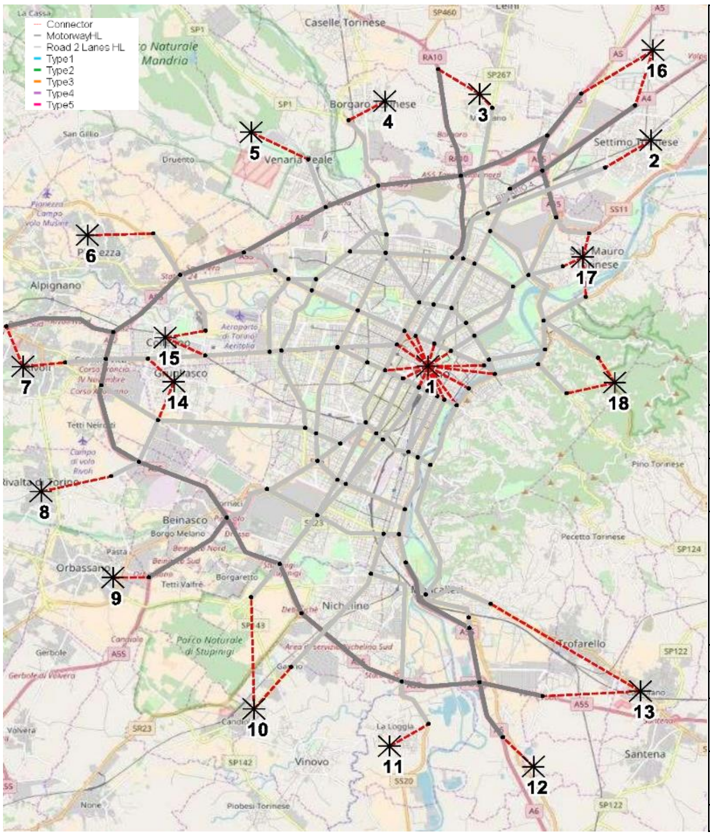


Fig. 28 Main steps of method procedure.

The method procedure is composed by different steps, as summarized in Fig. 28:

- *Modelling the* a priori *network*, using *OmniTRANS*, a traffic modelling tool for a high-level representation, main links, node and centroids are identified and classified on a georeferenced map. In the case study, useful in this thesis, the focus is on the Turin area in North of Italy. Only two main types of links are defined to simplify the network handling: “Motorway”, which includes the links of the urban motorways (average speed setting is 80 km/h), “Road2lanes” which includes all other links (average speed setting is 30 km/h). The choice of mean speed is based on author experience and considering the traffic condition of these type of roads: the “Motorway” speed includes the average speed for this road typology during congested periods and the “Road2lanes” speed includes the presence of secondary intersections along the links affecting traffic conditions. As regards the centroids, one internal centroid is located in the Turin city centre, whereas the external centroids are 17 and are chosen according to their relevance in terms of connections with the urban network, including the main high-speed road (A55 Turin Ring Road), for its relevance for freight distribution vehicles (Fig. 29). In fact, the two centroids valuable to investigate the role of last mile are the main freight terminal of Turin: Interporto SITO (number 9) and Pescarito (number 17). That said, other centroids are useful to cover the Turin area.



Centroids ID	Name
1	Turin City Center
2	Settimo Torinese
3	Mappano
4	Borgaro Torinese
5	Venaria Reale
6	Pianezza
7	Rivoli
8	Rivalta di Torino
9	Orbassano-Sito
10	Candiolo
11	La Loggia
12	Highway South (A6)
13	Santena-Trofarello-Cambiano-Moncalieri Chieri
14	Grugliasco
15	Collegno
16	Highway North (A5-A4)
17	San Mauro-Pescarito
18	Chieri

Fig. 29 A priori network of Turin area: Motorway in dark grey, Road2lanes in light grey and connectors in dashed red (Source: OmniTrans model).

- *Travel time from GPS data*. The positioning data are collected by light vans during their usual delivery operations in Turin, as provided by the tracking and tracing system already installed. The travel time calculation aims to better define the network features and road types for homogeneous time periods over the day. The time periods investigated was: 9.00 - 12.30 a.m. (H1) and 4.00 - 6.00 p.m. (H2). Each node of the a priori network is used to detect the time when every vehicle crosses the related road intersection and therefore to estimate the travel time along the links connecting to it. Mapping the vehicles at the nodes rather than along the arcs increases the chance to detect them for low sampling rates, since at intersections they spent usually more time. This operation is implemented through the creation of a round boundary area around each node of the network in an Open Source GIS System (QGIS) software (Pirra et al., 2018). The travel time along links is estimated without applying classic map matching procedures based on a link approach, as in (Holt & Sarder, 2017), but on a node one. Thus, the link travel time is derived computing the difference between the timestamps of the first recording in the boundary around the origin node and the first recording registered in the boundary around the end node. The algorithm includes only stop durations shorter than 120 seconds, compatible with traffic conditions, according to typical maximum duration of a stop for yielding or at traffic lights, whereas service stops are normally longer (Greaves & Figliozzi, 2008).

Fig. 30 Example of the matching between nodes and positioning data (Pirra et al., 2018)

- *Modelling the* a posteriori *network,* which represents an updated model with estimated travel time information and a more realistic road classification based on observed travel speed (Fig. 31). The decreasing trend of speed values, which come from the relation among the distance between nodes and the corresponding average travel time as shown in Fig. 32, was used as support to define 5 new classes of "road_types" and the corresponding average travel speeds are as following:
  - "Type1" →120 km/h
  - "Type2" → 105 km/h
  - "Type3" → 58 km/h
  - "Type4" → 29 km/h
  - "Type5" → 10 km/h.

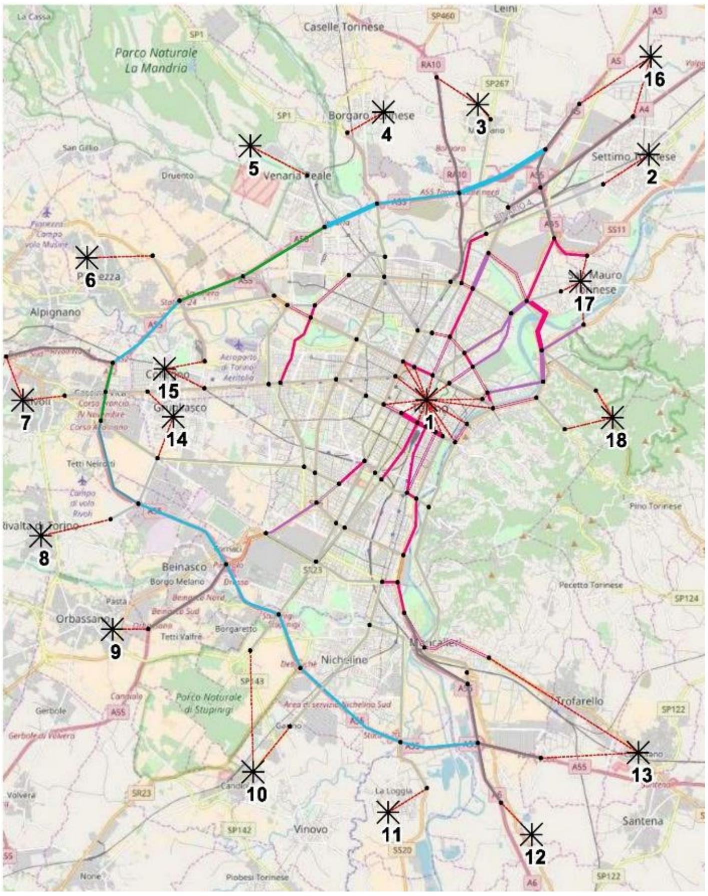


Fig. 31 The *a posteriori* network for period H1 (Pirra et al., 2018)

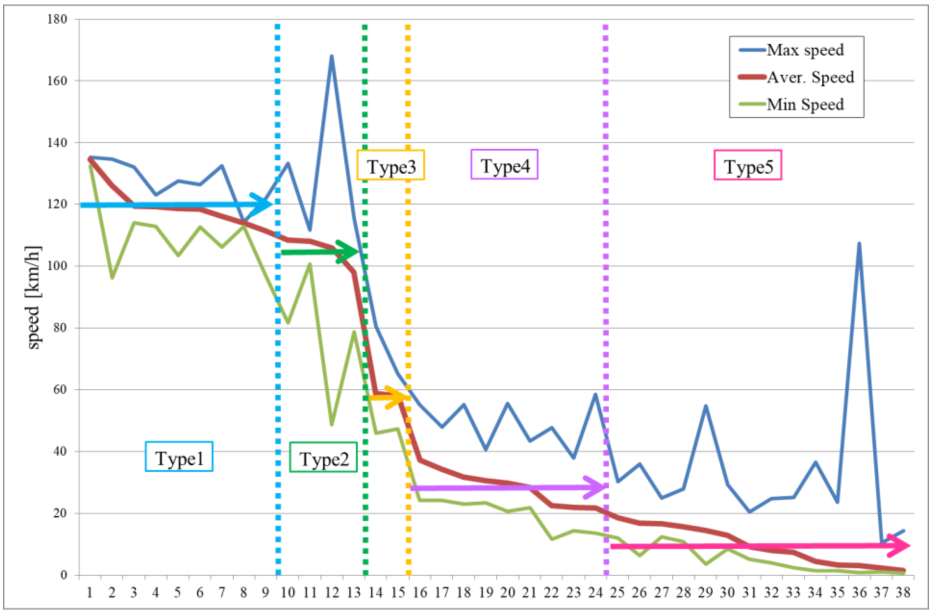


Fig. 32 Average speeds [km/h] found for the 38 arcs of the *a posteriori* network used to define the new road classification.

- *Model verification* to ascertain if the travel time values, as estimated to measure the accessibility among selected zones, provide consistent values if compared to those supplied by map providers on the web (Table 4) and *validation* of link classification to check if the simplified approach used gives acceptable results in the estimation of accessibility (Fig. 33).

Table 4 Travel time [min] comparison for different route between pairs of centroids using some commercial applications (example of some random trips).

Route	*A posteriori* network	Google Maps	Here	OSM
10080-10066	22	18-28	25	20
10066-10080	28	20-35	28	21
10087-10106	36	24-50	33	31
10106-10087	27	24-50	30	32
10080-10114	34	26-45	36	33
10114-10080	25	26-50	34	32

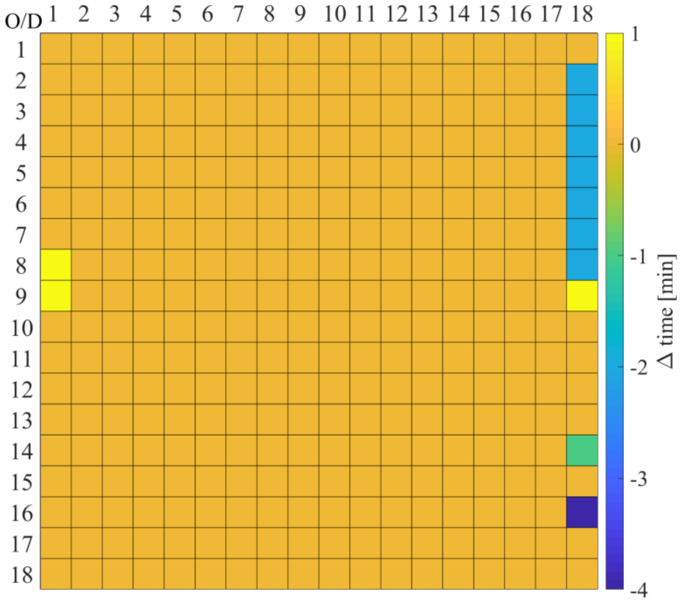
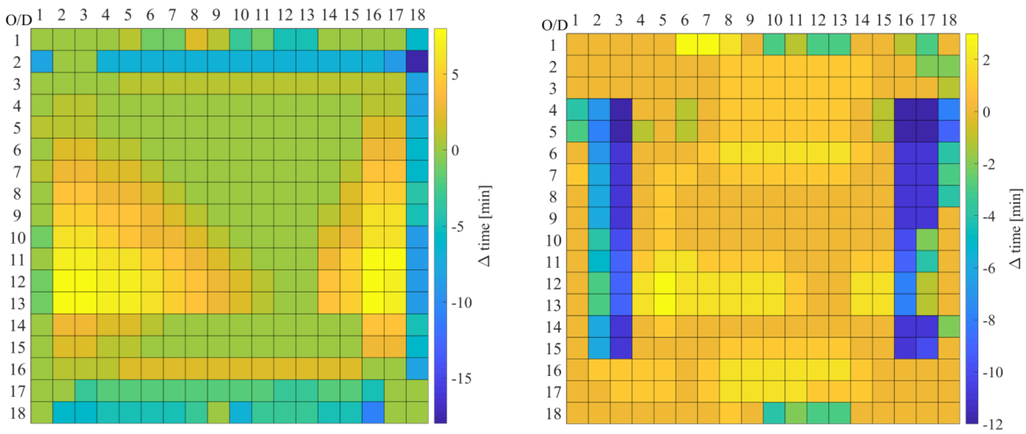


Fig. 33 Difference in the values of travel time [min] of shortest paths connecting centroids using network with real speed and the *a posteriori* (where speeds are those assigned with classification).

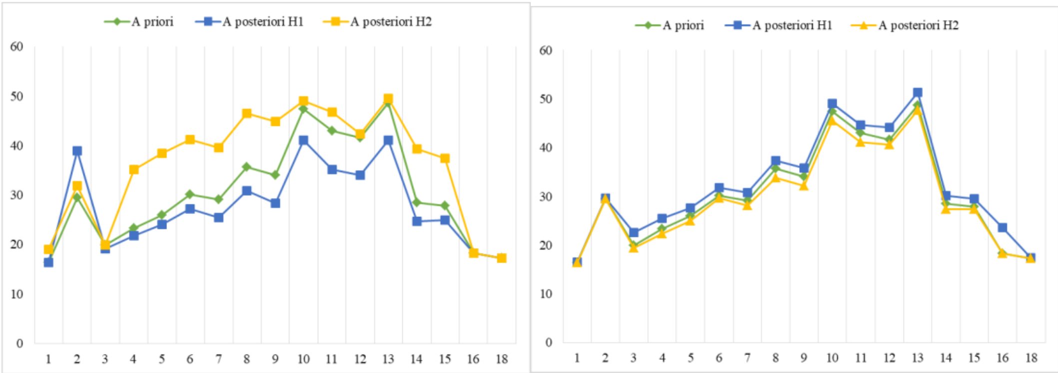
- *Accessibility matrix estimation* for the zones of the study area, considering skim matrices of travel times along the best route generated by the traffic modelling tool for *a posteriori* network. The influence of FCD integration on the travel time matrices is highlighted in Fig. 34. The richness given by the knowledge derived with the refinement of the a priori network is confirmed by the fact that 77% of values are different from zero in both cases.



(a) (b)

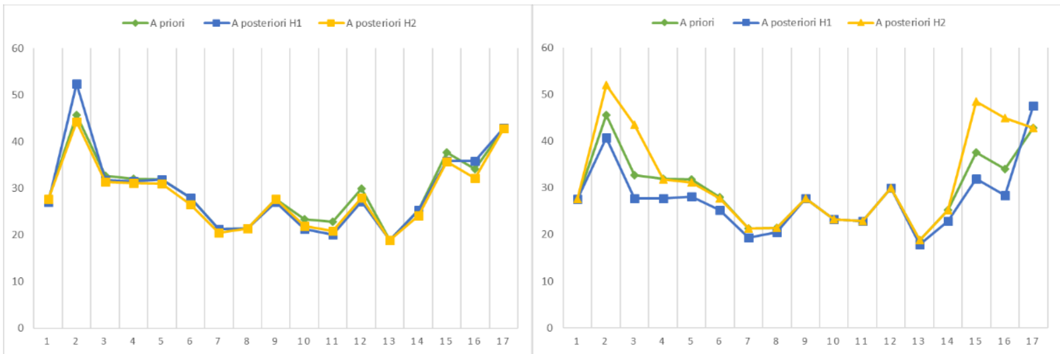
Fig. 34 Travel time difference [min] between the *a priori* and *a posteriori* scenarios for the time range H1 (a) and H2 (b).

Having shown the positive influence of FCD information on the travel time calculation and so on network classification, the main focus here is on the measurement of the accessibility to and from two crucial centroids for delivery operation: freight terminals of Pescarito and SITO (respectively Fig. 38 and Fig. 39). It is possible to see that the travel time to reach different city zones in Turin area can change depending on the period of the day and the areas themselves. This information, in terms of travel time, may be helpful to properly plan the delivery trips by goods fleet manager or to support the location decisions for city logistic structures.



(a) (b)

Fig. 35 Comparison between the travel time in three different scenarios to (a) and from (b) the depots area (Torino Pescarito - centroid 17).



(a) (b)

Fig. 36 Comparison between the travel time in three different scenarios to (a) and from (b) the depots area (SITO Orbassano - centroid 9).

Chapter 3

Rail-road intermodal terminal

The second chapter reported the technical and economic considerations on the competitiveness of rail-road combined transport solution. This third chapter provides details about the node of transport chain: the intermodal terminal. The *inland* terminals, to distinguish them from terminal container (typical for maritime transport), in fact play an important role, as underlined in previous sections, in the intermodal freight transport network to transfer loading units and achieve seamless cross-modal processes. Their efficiency contributes to competitiveness of intermodal transport which shifts medium distance freight journeys from road to other modes as required by European Policies. The challenging issue of optimizing terminal operations is crucial for the transportation chain effectiveness (Dotoli et al., 2017).

In Fig. 37 the flow diagram of the methodology proposed in the third chapter is presented. The starting point is the output of second chapter, namely the role of intermodal terminal on combined transport competitiveness (see flow diagram in Fig. 6). Two traceability matrices between performance indicators, phases of terminal process, actors and automatic identification are the first results. The choice of a specific category of technologies is a result of having identified the gate processes as possible improvement phases to increase the efficiency of the node. Then, different approaches are used to evaluate the impact of ITS implementation: the automatic identification technologies can improve terminal performance or helping in the operation of measuring the indicator itself. In the first case, the microsimulation model is built, while on field tests can evaluate the identification sensors as a support for monitoring for the measurement of indicators. The standard system architectures representation is the support to build the microsimulation model, to identify the process events to use as a reference for calculating the indicators and to investigate the layout of measures.

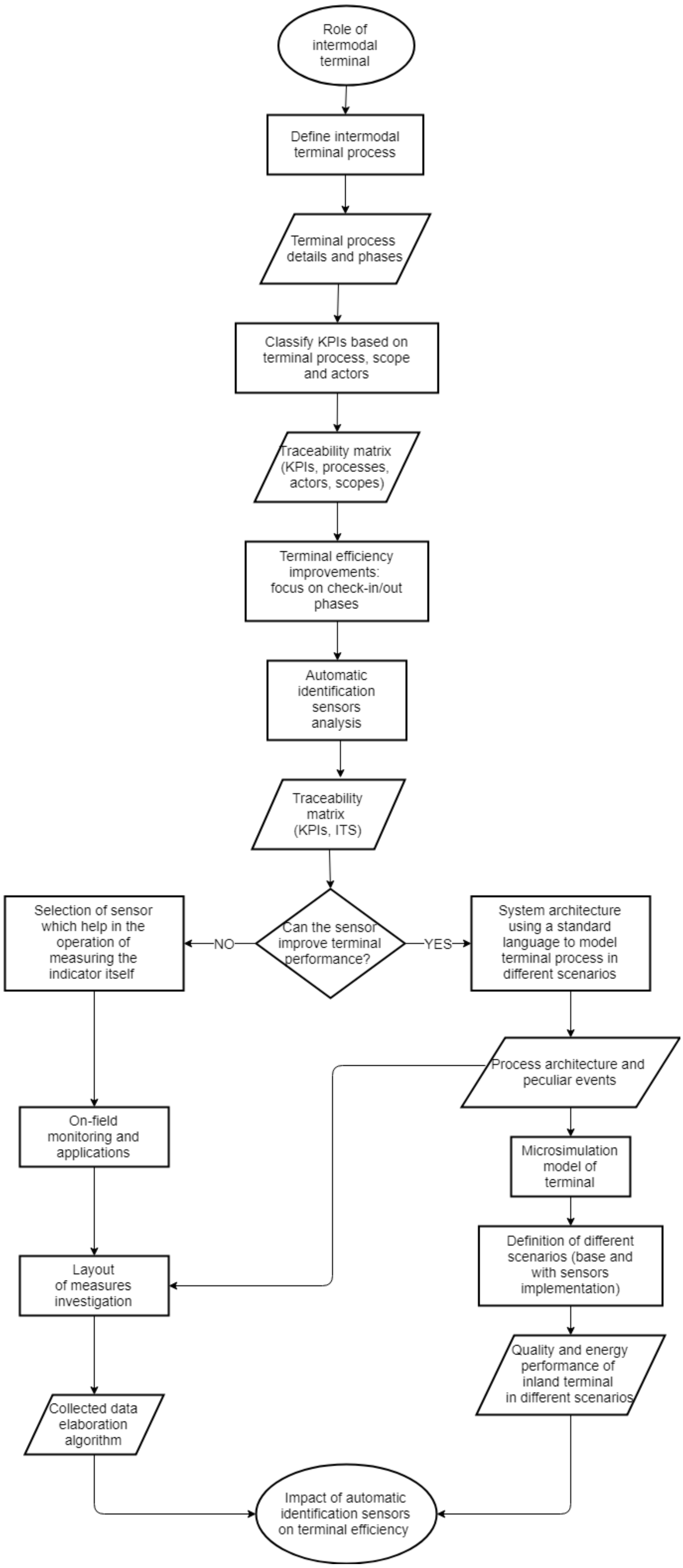


Fig. 37 Flow diagram of the method for assessing the role of intermodal terminals and the impact of automatic identification sensors (Chapter 3)

Inland terminals are key elements in the combined transport chain as they must guarantee a fast, safe and efficient transfer of intermodal loading units from one transport mode to another. Fig. 38 reports the distribution of rail-road combined terminals in European area.

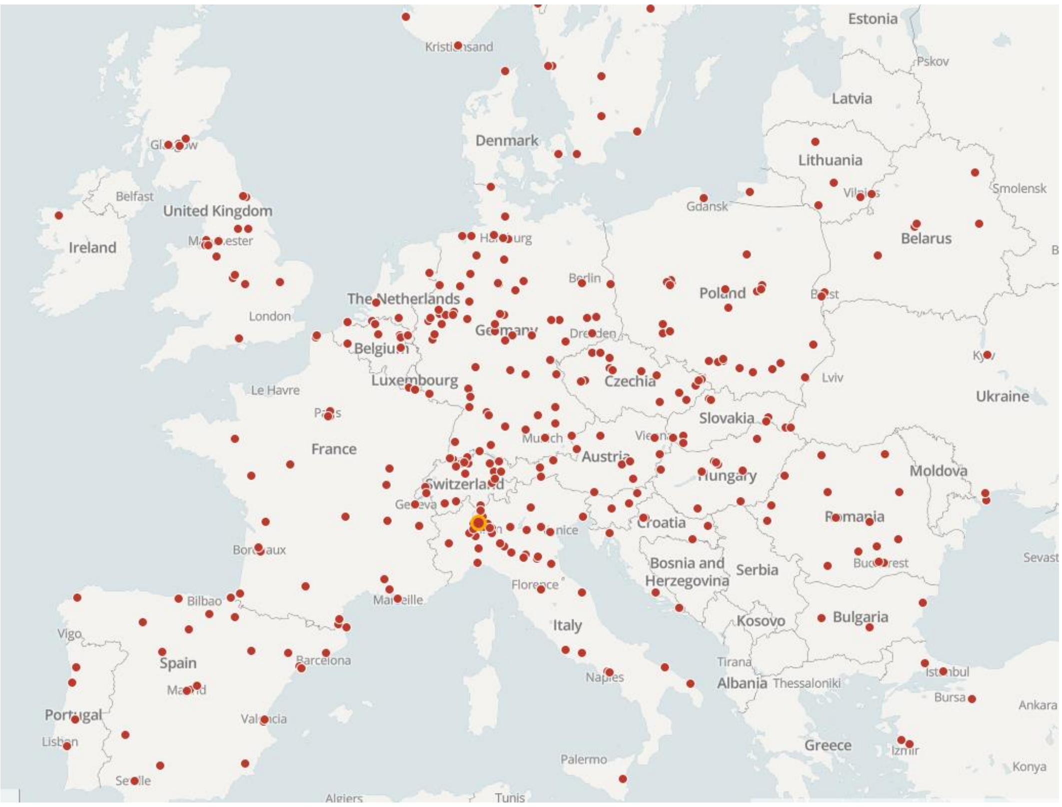


Fig. 38 Railroad terminals in EU (www.intermodal-map.com - latest internet consultation 24/10/2018)

Some definitions of this type of node are collected in the following:

- Rail-road terminals are interchange hubs between rail and road traffic. They are fitted with all the equipment required to handle and tranship loading units in a rapid and efficient manner: gantries and mobile cranes, computer systems integrating tracks, storage areas, transhipment areas and connections to roads and motorways (UIC).
- Terminal means the installation provided along the freight corridor which has been specially arranged to allow either the loading and/or the unloading of goods onto/from freight trains, and the integration of rail freight services with road, maritime, river and air services, and either the forming or modification of the composition of freight trains; and, where necessary, performing border procedures at borders with European third countries (EU Regulation 913/2010).
- Intermodal transport terminal is a place equipped for transhipment and storage of intermodal transport units (ITUs) between modes (Eurostat).

Fig. 39 shows a typical intermodal terminal section with road lanes, railways and handling equipment, the type in the picture is called gantry crane. The terminal layout and the location of different functions inside the terminal can influence the operations. In the area inside the terminal several elements may be present, as: tracks, storage areas for ITUs, areas for gates, offices and human services, technical warehouses, internal areas for the circulation of road vehicles, lifting and handling equipment, workshop, washing areas, storage for repairs, areas for gates, offices and human services. According to Ballis & Golias (2004) the main elements included in rail-road terminal are: rail siding for wagon both to transhipment that manoeuvres and other operations, buffer lanes for ITUs, loading and driving lanes for the trucks, gates and internal road network.

Fig. 39 Intermodal terminal Hupac Busto Arsizio-Gallarate: two examples of typical equipment (Zenucchi & Carboni, 2017)

Intermodal terminal might also have peculiar and increasingly-needed function: gateway (Fig. 40). This type of service to manage railway traffic is used in terminals for the direct ITUs organization between trains instead of complete wagons.

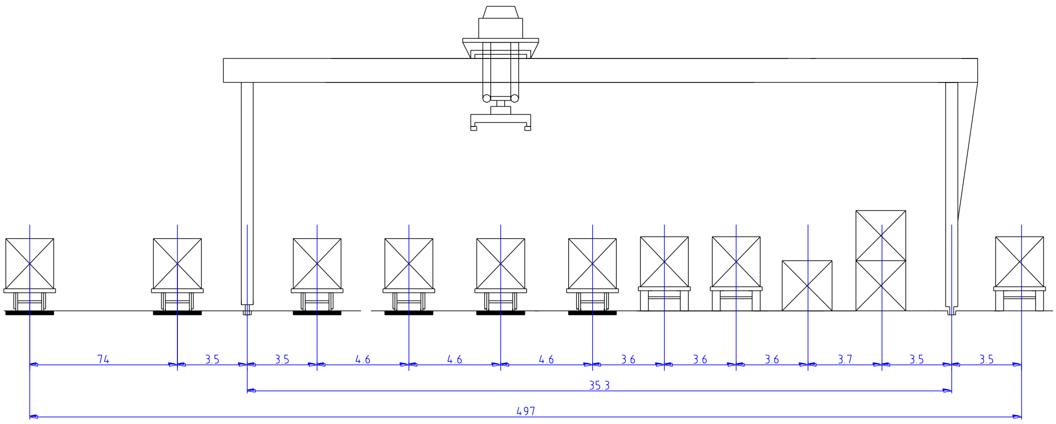


Fig. 40 Terminal gateway section (Hupac, Singen, Germania) (Dalla Chiara, 2015)

Intermodal freight terminals can be classified based on their capacity; for instance, Sirikijpanichkul & Ferreira (2005) stated the following categories:

- Small → less than 5,000 TEU’s
- Medium → 5,000 to 20,000 TEU’s
- Large → 20,000 to 40,000 TEU’s
- Super → over 40,000 TEU’s.

In Table 5 different example of intermodal terminals classification is reported, in this thesis the focus is on the first type: rail-road terminal.

Table 5 Example of classification of the existing Intermodal transport terminals in Europe (elaboration from (Ballis, 2004)

Type	Modes	Unit type(s)	Volume [ITUs per year] Small terminals	Volume [ITUs per year] Medium terminals	Volume [ITUs per year] Large terminals
I	Rail-Road Terminal	Swap bodies Semitrailers Containers	< 20 000	20 000 - 100 000	> 150 000
IIa	Barge-Road container terminal	Containers	< 30 000	30 000 - 50 000	> 50 000
IIb	Barge-Rail-Road Container terminal	Containers	< 50 000	> 50 000	not foreseen
IIIa	Maritime Full-Container terminal with Road and Rail connection	Containers	< 100 000	> 100 000	not foreseen
IIIb	Maritime Full-Container terminal with Road/Rail/Barge connection	Containers	< 200 000	200 - 500 000	> 500 000

3.1 Terminal processes

The terminal operations can be a lot and it is very important in terms of efficiency that these are strictly correlated. The list below provides some example:

- Handling operation by specific equipment
- Gateway operations
- Terminal area management
- Incoming/outgoing movements for trains
- Incoming/outgoing movements for road vehicles.

Each of these operations is managed by different specialized actors with procedures which can be very variable.

The actors involved in the process can be several and may vary depending on the terminal type. To better understand the following sections, here some considerations about terminal processes and operational roles in typical rail-road terminal are reported. The case study is on the intermodal terminal Hupac in Busto Arsizio - Gallarate (VA), one of Europe's largest transhipment facilities, with these main characteristics (Hupac SA, 2018):

- area of 245.000 m^2
- 12 portal cranes
- 300 trains are loaded and unloaded every week
- 421,000 load units in 2017.

The terminal operations in real-life environment are very complex, however, the observation of the actors and related roles which operate inside the rail-road terminal has allowed a better knowledge of each subprocesses (Table 6).

Table 6 Example of professional figures and their operation correlations

<table>
<tr><th>Role</th><th>Operation</th></tr>
<tr><td>Check-in operator</td><td rowspan="2">Incoming movements for road vehicles</td></tr>
<tr><td>Reception operator</td></tr>
<tr><td>Import operator</td><td rowspan="6">ITUs transhipment</td></tr>
<tr><td>Export operator</td></tr>
<tr><td>Crane driver</td></tr>
<tr><td>Area coordinator</td></tr>
<tr><td>Sector coordinator*</td></tr>
<tr><td>Operator for handling support</td></tr>
<tr><td>Train-the-trainer</td><td rowspan="4">Railway operations inside the terminal</td></tr>
<tr><td>Train verifier</td></tr>
<tr><td>Train driver and shunter</td></tr>
<tr><td>ACS Operator</td></tr>
<tr><td>Check-out operator</td><td>Outgoing movements for road vehicles</td></tr>
<tr><td>Operative process responsible</td><td>Manage the entire process</td></tr>
<tr><td colspan="2">* If the terminal area is divided in several sectors.</td></tr>
</table>

Fig. 41 and Fig. 42 show some main activities carried out by specific actor inside a typical rail-road combined transport terminal. These quite exhaustive schemes underline the complexity of terminal process and the need for good communication and organization to make the node more efficient. Automatic identification sensors or other technologies can help to achieve this aim, as better explain in section 3.3 for instance.

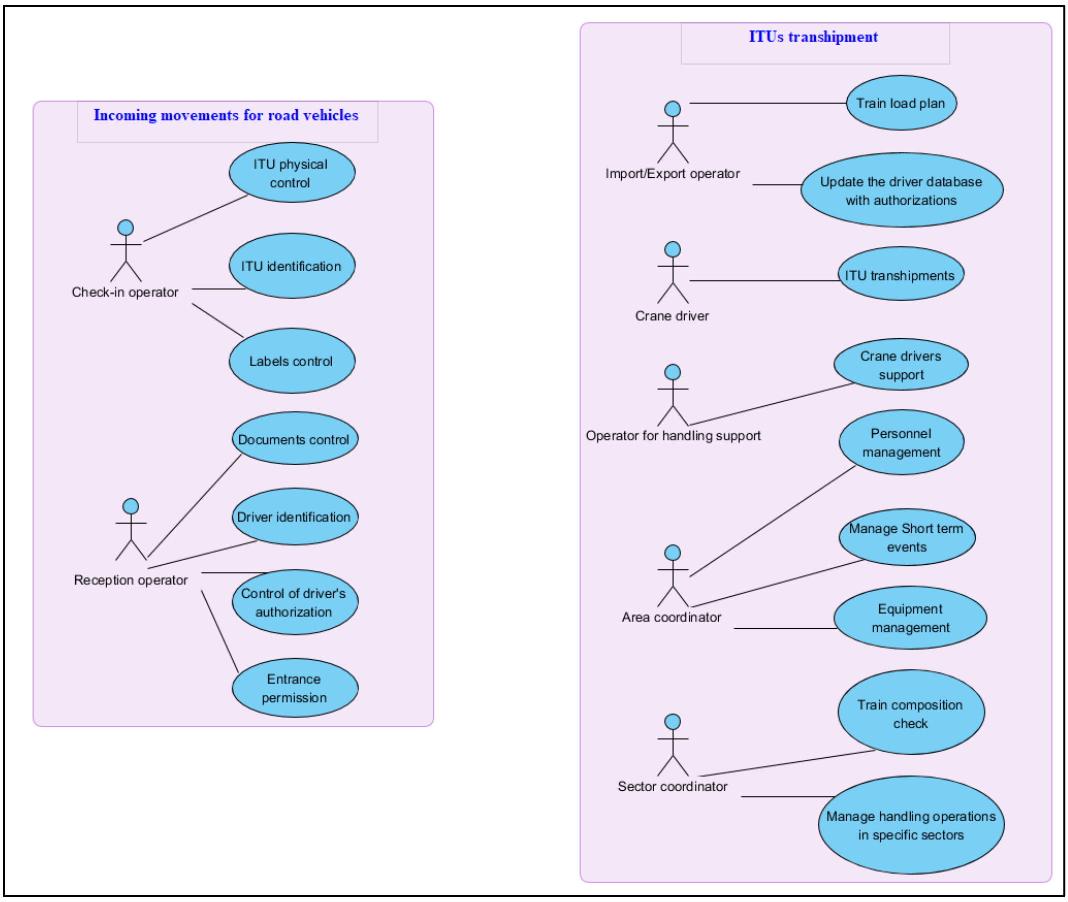


Fig. 41 Role and operations correlation using Use Case diagram (incoming movements for road vehicles and ITUs transhipment)

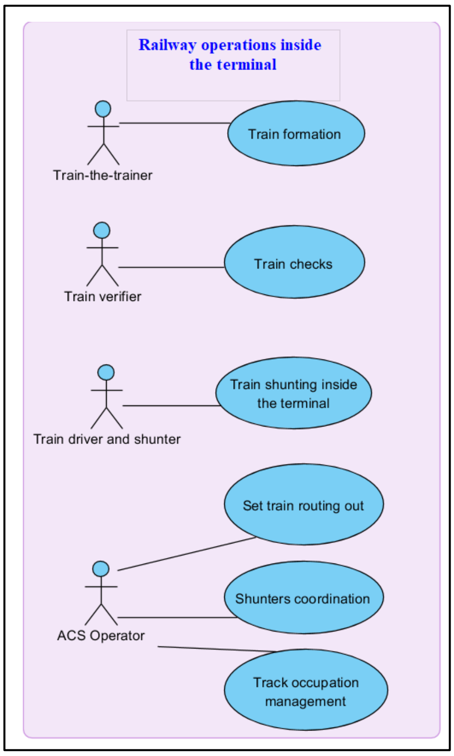


Fig. 42 Role and operations correlation using Use Case diagram (Railway operations inside the terminal)

To sum up, in Fig. 43 there is a synthetic scheme of a typical rail-road combined transport terminal with the main processes, in detail:

- *Check-in operations* for the trucks incoming at the terminal, including the inspection procedures and the documents management for goods and drivers. These two operations can also be performed in two distinct phases and places.
- *Loading or unloading operations* under cranes, from truck to railway wagon or vice versa, or even in special areas in case of technical stops or in parking lots for semitrailers.
- *Check-out operations* for the trucks leaving the terminal.

There are other procedures inside the node, that specifically involve operations from the railway side, as said before, but for the aim of the following sections the focus in on the road side of the terminal.

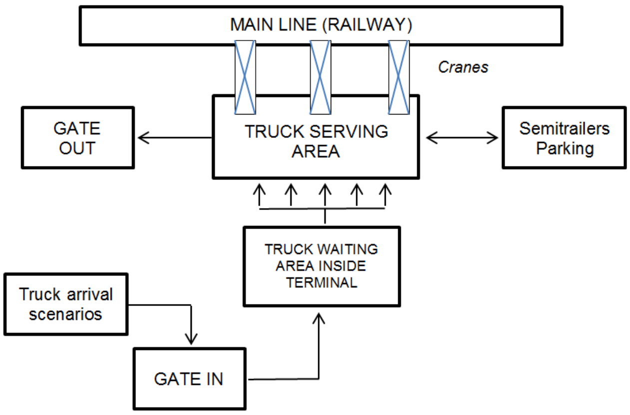


Fig. 43. Key elements in a typical inland terminal (Carboni & Deflorio, 2017)

ArchiMate is an open and independent modelling language that is supported by different tools (The Open Group, 2017). The standard provides a set of entities and relationships with their corresponding iconography for the representation of architecture descriptions. It is a common language to describe the construction and management of business processes, organizational structures, information flows, IT systems and technical infrastructure.

ArchiMate manages several views of the system: Business, Applications, Technology, Motivation, Implementation and Migration, that are developed in interconnected layers by means of structural relationships.

In Fig. 44 the terminal process, from the road side point of view, are represented using the business layer because allows the analysis of the process oriented to the services provided. In the business layer the active entities are the subjects (e.g., *business actors* or *business roles*) that perform behaviour such as *business processes* or *functions* (capabilities). The actor can cover different roles to perform the functions collected in a process, for example the check-in operator (CI operator) can have the role of inspector and identifier. More in detail, the process was split into four *business service* (according to ArchiMate nomenclature): check-in, data management, transhipment and check-out. The transition between one service and another is identified with one *business event*, such as the "authorisation provided" which means that the check-in is end and the data check can start. The services are composed by several *business process* and *functions*, for instance the check-in service contains two main processes: identification and inspection, the first one includes the plate and ITU's code reading while the inspection regards the control of unit labels, its integrity and its possible damages. The second service, that occurs at the terminal entrance, is the document check called "data management" in Fig. 44. During this service the reception operator must control the transport documents of the unit and the driver identity, then if the documentation is compliant, the driver is informed about the loading or unloading sector (*business event*=sector assigned). The details about the transhipment service are out of the scope of this thesis. Finally, the check-out service take place at the exit gate where the check-out operator (CO operator) verifies the correct association between the truck's plate and the ITU's code. The truck process inside a typical intermodal terminal ends with the event "truck exit".

In general, these types of representation can be useful to explain to stakeholders, as terminal operators, the effect of ITS implementation in their process (see section 3.3).

To show also some aspects of railway side in Fig. 45 are reported the scheme of train entrance service, where two process take place: the shouting and the train composition check. The event that identifies the actual entrance of the train to the terminal are the "MAD" (train available). The operations are performed on *business objects*: train, ITU and wagon.

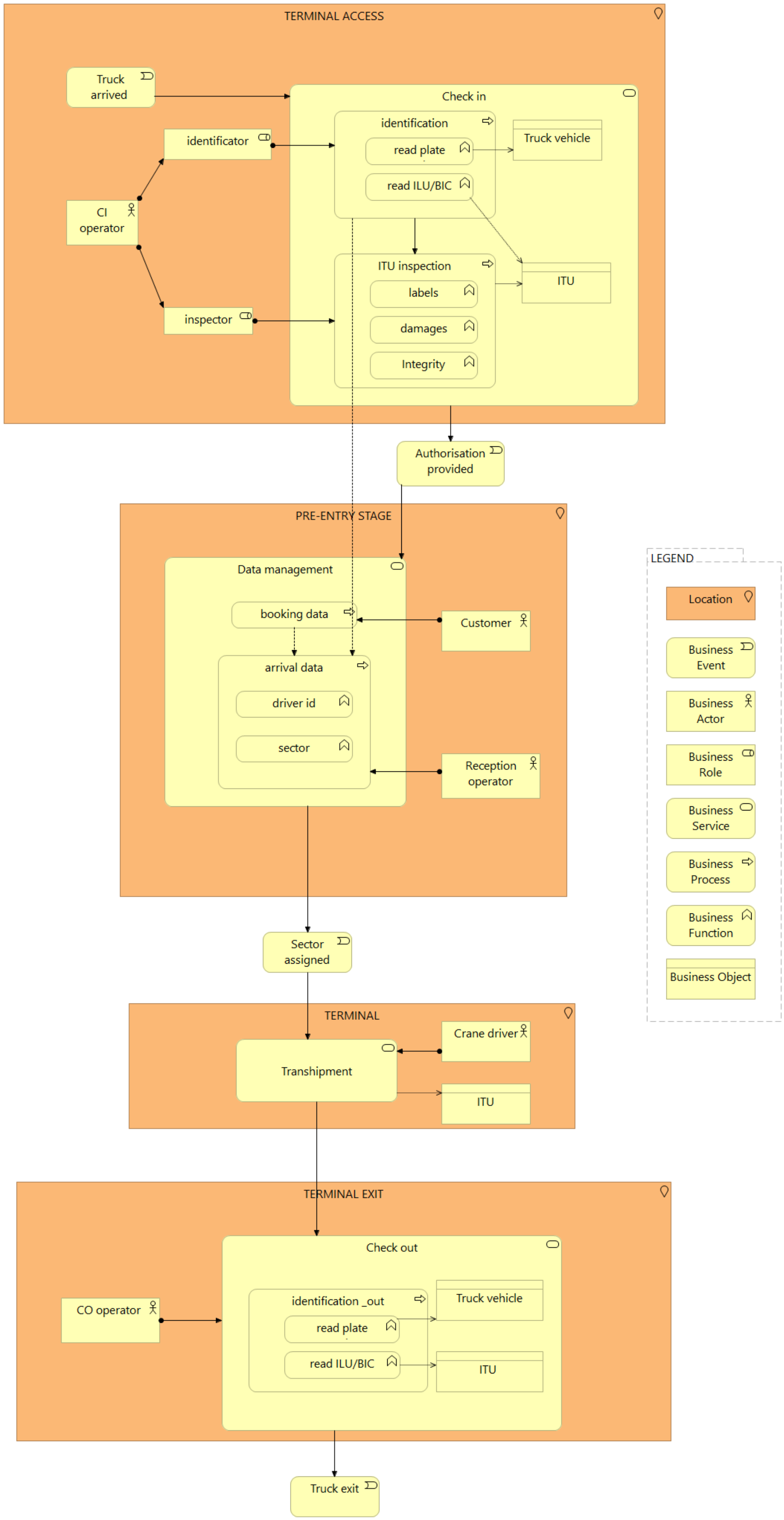


Fig. 44 Terminal process (focus on road side): business layer view

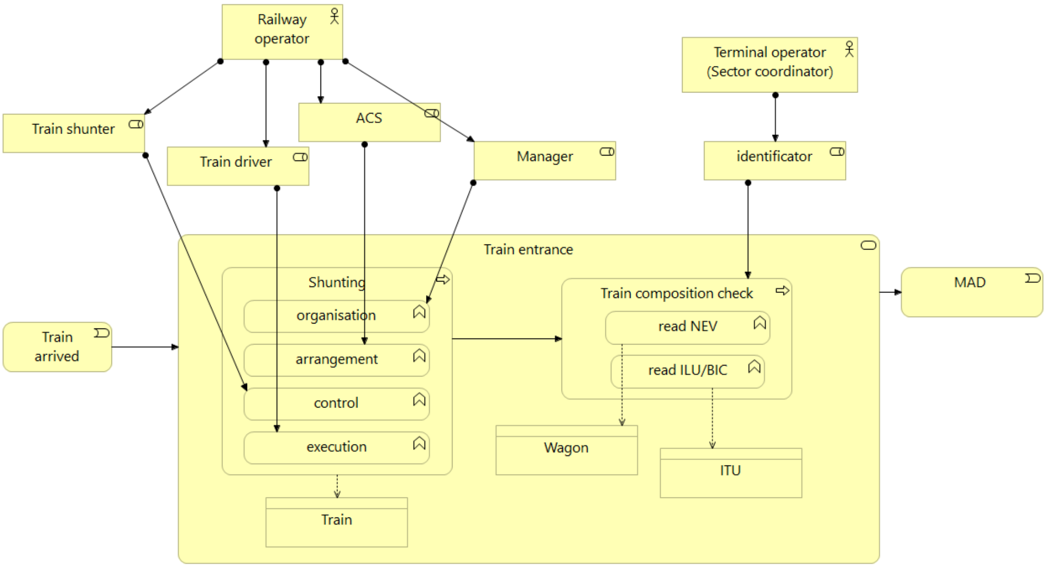


Fig. 45 Terminal process (focus on train entrance): business layer view (see Fig. 44 for the legend)

3.2 Performance indicators

The intermodal terminals have a fundamental role, therefore an impact, on entire logistic chain of combined transport both on economic, quality and efficiency point of view.

The Key Performance Indicators are variables defined to measure the efficiency of the process by different viewpoints, such as economic, energy or throughput. Concerning their basic requirements, performance indicators must be: clear, coherent, compatible, controllable, complete, pertinent and feasible. Identify proper performance indicators is useful to compare different scenarios and provide measurements to support decisions.

In general, performance indicators can be classified according to the chosen point of view into two main classes:

- OLA (*Operational Level Agreement*), operational indicators with an internal valuation of the process.
- SLA (*Service Level Agreement*), external valuation of the service from user point of view.

The European project Intermodel EU (Martín et al., 2017) proposed a complete state of the art about performance indicators for rail-road combined transport. First, they grouped the actors in three classes:

- *Public authorities*
- *Operators* (terminal, railways, roads...)
- *Investor*

Second, they grouped the scope into other classes, based on the part of transport chain involved:

- *Intermodal terminal,* to measure its efficiency;

- *Hinterland,* to measure the impact of road connections;
- *Railway network,* to measure the impact of railways connections.

The actors and the scope classes proposed in the following sections are quite different.

In Table 7 some performance indicators are proposed, thanks to an elaboration from (Martín et al. ,2017), (OECD, 2002) and (Department for Transport, 2009). Each indicator is classified based on its category and scope.

Table 7 Key Performance Indicator for rail-road combined transport

Category	Indicator	Description	Unit	OLA	SLA	Scope
OPERATION	Terminal throughput	Handled units per hour, per day...	n.UTI (TEU)/ (hour, day, month, year)	x		Terminal
	Equipment utilization	Percentage of equipment utilization	equipment used/tot equipment [%]	x		Terminal
	Gate utilization	Percentage of gates utilization	n. gates used/tot gate [%]	x		Terminal
	Labour utilization rate	Total labour content divided by the sum of labour content and total idle time.	Labour content/(labour content+idle time) [%]	x		Terminal
	Rail track occupancy	Percentage of track occupancy respect the total terminal area	m^2 track/tot area m^2 [%]		x	Terminal, Rail
	Truck turnaround time	Total time spent by truck inside the terminal	min	x	x	Terminal
	Entry waiting time	Total time spent by truck in queue before entering	min		x	Terminal
	Shunting times	Total time spent for shunting activities inside the terminal	min	x		Terminal, Rail
	Total cycle time (distance based)	Total time for door-to-door transport per ITU	min (or day)		x	Combined
	Equipment availability	The percentage of time during which an equipment is available to run.	min	x		Terminal, Rail, Road
	Container dwell time in terminals	Truck waiting time inside the terminal	min		x	Terminal
	On-time terminal departures	Number of trains departed on time (defined) from the terminal.	n. on time train/tot train departured		x	Rail
	Wagon availability	The percentage of time during which a wagon is available to run.	min (or day)	x		Rail
	Locomotive availability	The percentage of time during which a locomotive is available to run.	min (or day)	x		Rail
	Shipment tracing capabilities	The percentage of train traced	n. train traced/ tot train		x	Rail
	Average km per litre	Average fuel consumption per road vehicle	km/l	x		Road
	Total km run	The sum of total vehicle-km	km	x		Road
	Total empty miles run	The sum of total empty vehicle-km	km	x		Road
	Empty running total	Percentage of empty trips to total trips	empty veh-km/tot veh-km[%]	x		Road
	Average vehicle fill	Percentage of vehicle fill to total trips	filled vehicle/total veh [%]	x		Road

	Total number of overloads	Total number of overloaded vehicles	n of vehicle	x		Road
	Headcount	Workforce in terms of number of people employed	n of people employed (/day, month, ITU or...)	x		Terminal, Rail, Road
	Number of departures in time	Total number of trains on time in certain period	n on time trains/tot trains [%]		x	Terminal, Rail
FINANCE/ECONOMY	Profitability	Identify the relationship between the costs and benefits	Cash flows/Investment	x		Terminal
	Revenues per unit	Revenue per transported unit (per defined period)	€/ITU	x		Terminal
	Average cost per unit delivered	Sum of all costs (rail, road and terminal)	€/ITU	x		Combined
	Benefits per unit	Benefits per transported unit (per defined period)	€/ITU	x		Terminal
	Price Door-to-door (distance-based)	Price to move ITU from origin to destination based on the distance covered	€/ITU		x	Combined
	Price Door-to-door (value-based)	Price to move ITU from origin to destination based on the goods value	€/ITU		x	Combined
	Price Door-to-door (time-based)	Price to move ITU from origin to destination based on the time spent	€/ITU		x	Combined
	Willingness to negotiate	Qualitative aspect that indicate the price flexibility	(qualitative: for example, good, medium, bad…)		x	Combined
	Invoicing accuracy	The accuracy level of invoicing	[%]		x	Combined
	Total whole vehicle cost	The total cost for road vehicle per unit delivered	€/km	x		Road
	Average running cost	The total cost to move road vehicle per unit delivered	€/km	x		Road
	Average standing cost	The total standing cost for road vehicle per unit delivered	€/km	x		Road
	Average driver cost	The total cost for driver per unit delivered	€/km	x		Road
	Total maintenance cost	The total maintenance cost for road vehicle per unit delivered	€/km	x		Road
QUALITY	Easiness of entry and exit from highways	Driving in time or distance from highways to terminal	min or km		x	Terminal, Road
	Easiness of entry and exit from rail network	Driving in time or distance from rail network to terminal	min or km		x	Terminal, Rail network
	Timeliness reliability	Percentage level of reliability to published or quoted estimated time of arrival	[%]		x	Combined
	Shipment tracing/asset visibility	The level of visibility for shipment tracing	(qualitative: for example, good, medium, bad…)		x	Combined
	Feedback across all sections of the chain levels	The quality of feedback across the point of the transport chain	% or qualitative (for example good, medium, bad…)		x	Combined
	EDI/Common documentation	The level of use of EDI or common documentation	% or qualitative (for example good, medium, bad…)		x	Combined

	Flexibility of routings	The level of flexibility in rerouting the transport	(qualitative: for example, good, medium, bad…)		x	Combined
	Late deliveries	Percentage of total late deliveries	n. late deliveries/tot deliveries	x	x	Combined
ENVIRONMENT	Total energy consumption	Total energy consumption in terminal per num. of handled units	tot kwh consumed/tot n of handled ITU [kWh/ITU]		x	Terminal
	CO, NOX, SOC, PM emissions	Total emissions during specific period (also per num. of handled units)	gX/day (or hour, year…) [X= CO, NOX, PM..]		x	Road, Terminal
	Total fleet CO_2	Total fleet CO_2 emission per period	gCO2/day (or hour, year…)		x	Road
	Average fleet CO_2	Average fleet CO_2 emission per period	gCO2/day (or hour, year…)		x	Road
SAFETY / SECURITY	Num. of road accidents	Total number of road accidents for the fleet per period	n of accidents		x	Road
	Num. of railway accidents	Total number of rail accidents for the fleet per period	n of accidents		x	Rail
	Percentage of accidents related to hazard cargo	Total number of road accidents which involve hazard cargo per period	n of accidents		x	Road
	ITU lost	Annual losses of ITU	% of ITUs/per trip/per annum lost	x	x	Combined
	ITU damage	Annual ITU damages	% of ITUs/per trip/per annum damaged	x	x	Combined

Due to the aim of this thesis the focus is on the indicator for the rail-road terminal process. More specifically, some of these which are related to the implementation of sensors to detect ITUs and for vehicles automatic identification in the terminal accesses are used hereafter.

Based on the scientific literature and on the Table 7, a set of selected performance indicators for inland terminals is identified and classified, considering the terminal sub-process, the actor involved (main operational roles on road side point of view) and the scope (Table 8).

In this case, according to Carboni & Deflorio (2018) the scopes are:

- *Safety*, the identification of people who enters and leaves the area, for instance, is useful in terms of safety and security for terminal operator. In this sense, the time required is not relevant, but it is linked to the automation of the process. Nevertheless, less queue means more safety and security because the terminal operator cannot ensure a controlled situation for users as it happens outside the terminal;
- *Environment*, less time spent by trucks inside the terminal, especially during queues with the engine on, less pollutant emissions are produced;
- *Efficiency*, since reduced times in procedures can increase productivity and all the selected indicators are a measure of the terminal throughput.

Define a picture as complete as possible of the performance indicators for an intermodal terminal was important due to the fragmentation in the scientific literature even if only a selection of them will be used later in the work presented in this thesis. In detail, the performance indicators grouped as “Truck check in/out” in Table 8 and the ITU turnaround time will be used in setting the architecture layers in section 3.4.1 whereas the turnaround time for vehicles will be the main indicator for the micro-simulation reported in section 3.4.2.

Table 8 Traceability matrix between chosen performance indicators, classified based on sub-process, related scope and main actors directly involved in the process.

Indicator		***Description***	***Unit***	***Actor***		***Scope***		
				Terminal Operator	**Truck driver**	**Safety/Security**	**Environmental**	**Efficiency (Throughput)**
Inland terminal global indicators								
V_{ts}	Transhipment volume (Throughput)	Tot TEU/day (week, year) or Tot ITU/day (week, year)	[n ITU/day]	√				√
U_{ts}	Utilisation rate	Ratio between throughput and theoretical capacity	[%]	√				√
C_{ts}	Transhipment costs	costs €/ITU or €/h	€/ITU	√	√			√
$Tcut_{ts}$	Cut-off Time	Time interval between the last ITU delivered and the train departure	[min]	√				√
Tt_{ITUi}	Turnaround time UTI_import	Total time inside the terminal	[n days]	√				√
Tt_{ITUe}	Turnaround time UTI_export	Total time inside the terminal	[n days]	√				√
D_{ts}	Damage frequency	Number of ITU damages / year	[n UTI/tot ITUs per year]	√	√	√		
L_{ts}	Loss frequency	Losses ITU / tot ITU per year	[n ITU/ tot ITU]	√		√		
R_p	Process utilization rate	For each process is the ratio between the arrival rate and service rate (p= name of process)	[%]	√	√			√
E_{ITU}	Energy consumption per ITU	kJ/ITU or kWh/ITU	[kJ/ITU]	√			√	
DbA	Noise emission	dBA/h	[dBA/h]	√			√	
CO_2	CO2 emission	Average emission of CO_2 per ITU or per day	[g of CO_2/ day]	√			√	
PM	PM10 concentration	PM10 Concentration per ITU or per day	[μg/m³ per day]	√			√	
Transhipment								
T_g	Crane rate	Number of handled ITU per hour	[n ITU/h]	√				√
Tm_g	Average loading/unloading time	Time needed for loading or unloading per ITU	[min]	√				√

Train check in/out								
D_t	Train departures delay	Ratio between late and total trains	[%]	√				√
A_t	Train arrival delay	Ratio between late and total trains	[%]	√				√
Truck check in/out								
$T_{ch\text{-}in}$	Physical check-in time	Time interval between the beginning and the end of inspection procedures	[s]	√	√	√		√
T_{doc}	Documents exchange time	Time interval for document exchange	[s]	√	√	√		√
Q_{t_in}	Entrance queue	Percentage of trucks queuing before entering	[n of veh]		√		√	√
W_{t_in}	Entrance waiting time	Average waiting time at the entrance	[s]		√		√	√
T_t	Turnaround time	Time interval between the beginning of physical check-in and check out	[s]	√	√		√	√
W_{t_out}	Exit waiting time	Average waiting time at the departure	[s]		√		√	√
Q_{t_out}	Exit queue	Percentage of trucks queuing before exiting	[n of veh]		√		√	√
$T_{ch\text{-}out}$	Check-out time	Time interval between the beginning and the end of check out procedures	[s]		√	√		√
T_a	Avarage waiting time under crane	Time interval under crane	[s]		√	√	√	√
Import: from rail to road; Export: from road to rail								

3.3 Automatic identification sensors

«Intelligent Transport Systems (ITS) integrate telecommunications, electronics and information technologies - in short, 'telematics' - with transport engineering in order to plan, design, operate, maintain and manage transport systems. This integration aims to improve safety, security, quality and efficiency of the transport systems for passengers and freight, optimising the use of natural resources and respecting the environment. To achieve such aims, ITS require procedures, systems and devices to allow the collection, communication, analysis and distribution of information and data among moving subjects, the transport infrastructure and information technology applications». [ITS EDUNET, 2009]

The second priority action of "Piano di Azione Nazionale sui Sistemi Intelligenti di Trasporto (ITS) (2014)[12], promotes the use of ITS for multimodal transport and transport management logistics, according to open and interoperable platforms. The use of ITS technologies can support the process in intermodal terminal to guarantee interoperability and continuity of interchanges between different modes. Some operations suggested in the Plan are:

- release of basic information (traffic situation near the logistic nodes, areas of movement available);
- streamlining of administrative procedures;
- circulation fluidization near the intermodal areas to avoid loss of time due to congestion and reduce environmental impact;
- minimization of waiting times and storage of goods;
- tracking and tracing of vehicles and loads for the transport of dangerous goods, using radio frequency (RFID) and automatic tracking systems (GPS / EGNOS/ Galileo);
- use of technologies for detecting vehicle and load status information;
- introduction and combination of ITS technologies to couple the tracking of vehicles to goods.

It should also be noted that *Regulation (EU) No 1305/2014* underlines some of previous points, as the definition of basic information, the important role of tracking and tracing and the matching between vehicles and goods.

Numerous ITS applications can be found pertaining to road and multimodal transport. As previously mentioned, all of them generally have the following basic technological supports or components in common (Dalla Chiara et al., 2017), in Fig. 46 some of these are reported. In particular, the ITS components categories selected are systems for: location, identification and data collection. The first technologies (Automatic Vehicle Locating System) identified the unit, people or vehicles positions during their path, while the Automatic Identification System

[12] Application of Directive 2010/40/EU.

automatically detect information about unit, people or vehicles. Finally the systems for traffic monitoring aim to collect traffic unencoded data (Dalla Chiara, Barabino, Bifulco, & Corona, 2013).

In some European intermodal terminals, especially in ports, many of these applications are present.

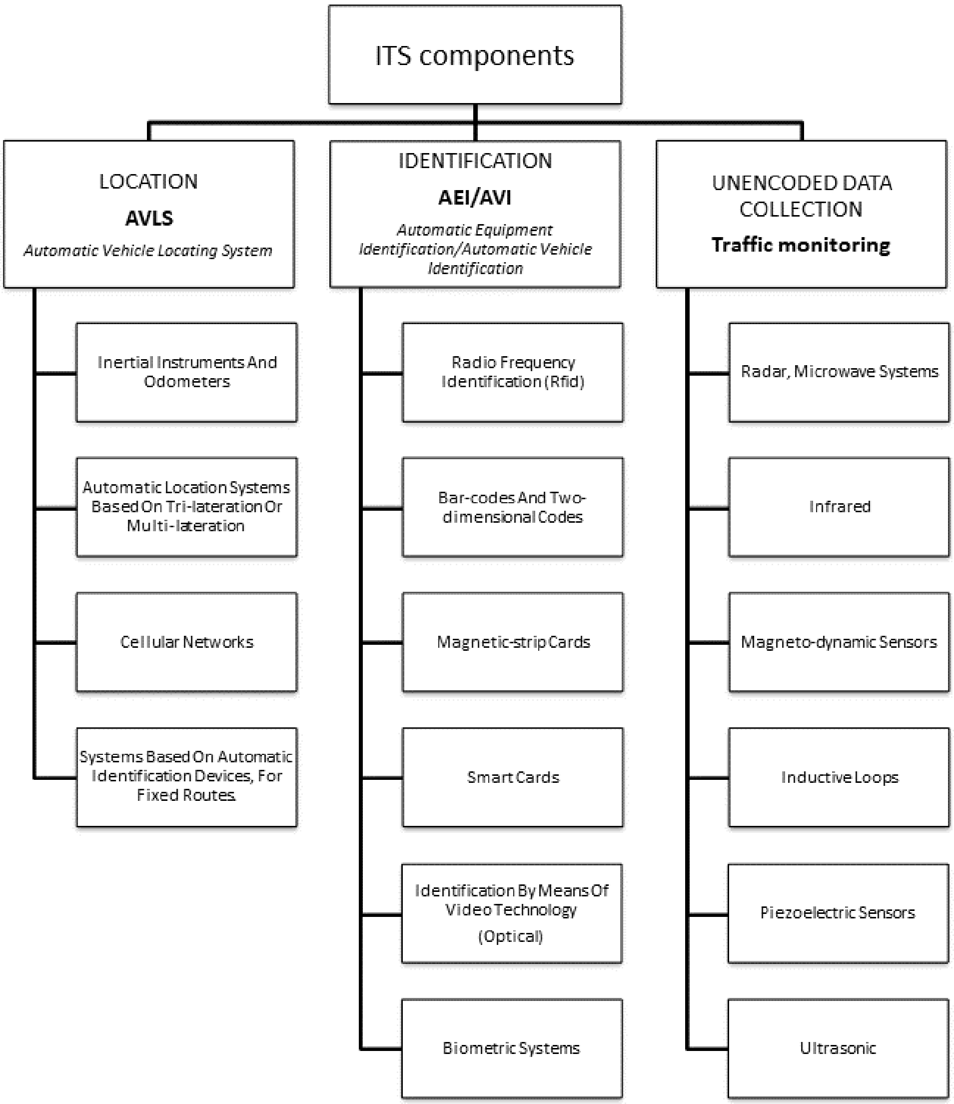


Fig. 46 Example of ITS components classified based on their purpose.

Intermodal transport requires also a complex data exchange due to its heterogeneity and the variety of actors with respect to the unimodal solution. Some ICT solutions could support these data flows, and consequently the rail-road combined transport process, ensuring accuracy, quality, reliability and promptness (Carboni & Deflorio, 2018).

The implementation of innovative technologies probably means additional costs, but if the solution has been properly assessed, the costs can be balanced by the improvement in quality and efficiency (results from literature review in section 1.3).

In general, the control and management of transit points for freight transport through ITS solutions are useful for intermodal terminals or port gates, as they can simplify and speed up operations as well as avoid possible human errors.

The interest of the current work is on the second column of Fig. 46, the automatic identification of ITUs and vehicles during the gate in and out operations for road access in a railroad terminal. Manual identification of ITU, although adopted in many terminals, may cause a chance of errors or more time than a procedure based on automatic reading (Wu, Liu, Chen, Yang, & He, 2012).

The evolution of the automatic identification of vehicles entering in freight villages, intermodal terminals or ports in Europe has been facilitated by the introduction of a standardized codification for containers and ITUs: the abovementioned EN 13044 of 2011 and ISO 6346 of 1995.

The systems can be situated in different place inside the inland terminal, to monitor the entire process or some part of this. Focusing on the automatic identification, the two most popular solutions are radio frequency identification (RFID) and optical character recognition (OCR) technologies (Yoon et al., 2016) (Carboni & Deflorio, 2018):

- *Optical Character Recognition (OCR) systems*,

based on optical identification, allow the recognition through the analysis of high-resolution images. Both ILU and BIC code are clearly printed recognizable with OCR systems, allowing significant simplifications and automatic procedures, so can contribute to enhancing port or inland terminal efficiency. Actors of intermodal logistic chain can identify the ITU owner if the code is registered and published. The first application of OCR system to automatic container identification was in 1998 in the port of Shanghai United Asia Container Depot. Automatic identification with optical sensors, in addition to reading ILU or BIC code and truck license plate, can detect the IMO label, chassis number and record video images of ITUs useful in case of dispute for damages reported. In general, systems based on visual identification enable the recognition of an object - not only the ITU Code, but also the trailer numbers, lorry license plates or dangerous goods labels - through the analysis of a high-resolution image. A portal equipped with cameras is usually located at the terminal or port gates to automatically capture and process container data, and, at the same time, to obtain high-resolution images for the recording of the condition of lorries and ITUs (Fig. 47 and Fig. 48). In Italy some applications of OCR technology are present in the Terminal Container Ravenna ("Fast Corridor" project) and in the Terminal Container of Genova Port.

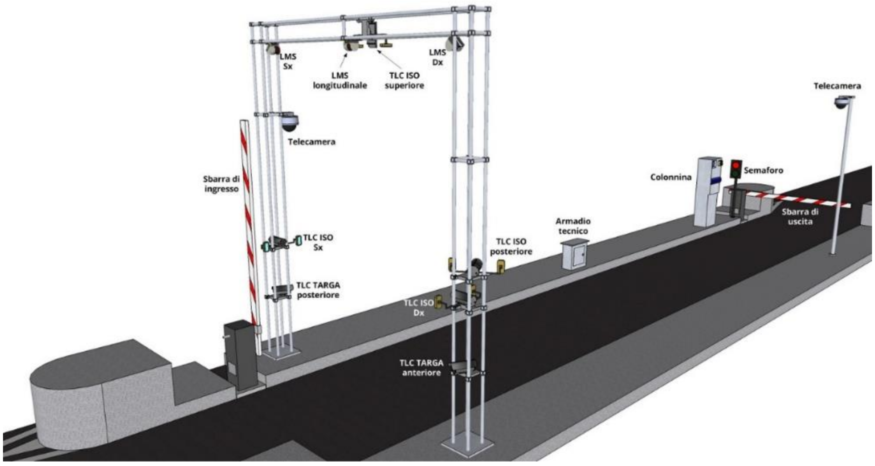


Fig. 47 Terminal gate with OCR infrastructure (https://www.aitek.it/automazione-varchi-sesamo-gate/)

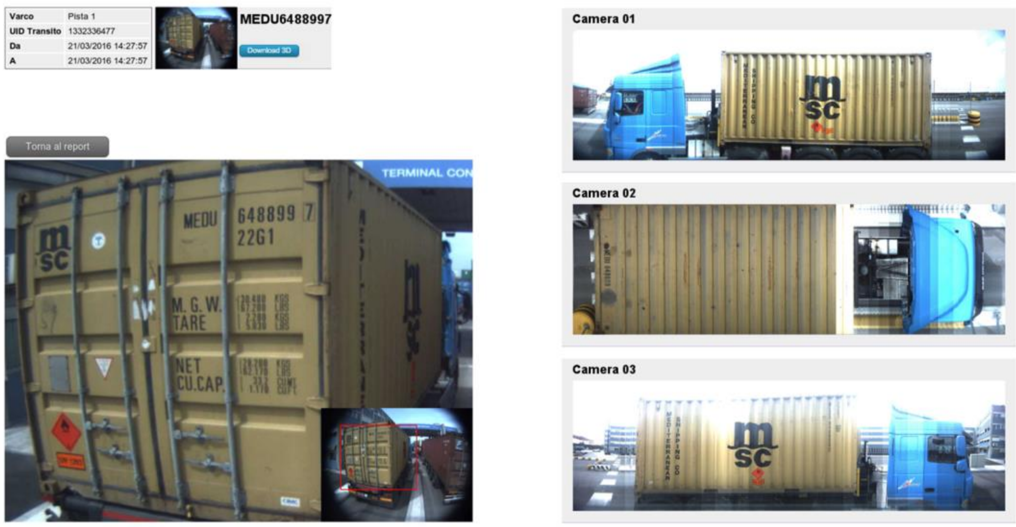


Fig. 48 Typical OCR software interface (https://www.aitek.it/automazione-varchi-sesamo-gate/)

- *Radio-Frequency Identification (RFID),*

based on the radiofrequency data transmission between a transponder (tag) and a fix point (reader) by a dedicated short-range communication (DSRC) (Fig. 49). The tag can be classified in:

- Passive, if uses the radio energy transmitted by the reader and operates over distances of a few meters;
- Active, if has an on-board battery and periodically transmits its ID signal, this type can cover hundreds of meters;
- Semi-passive (or battery-assisted passive), if has a small battery on board and is activated when in the presence of an RFID reader.

The RFID sensors read the tag to identify the vehicle and transport units, while security cameras are necessary to record high resolution images into the storage unit of the ITU conditions before the entrance to the terminal. The RFID solution requires that the object to be detected is equipped with a specific tag: it could be on the ITU, on the vehicle (e.g. automatic road tolling) or on the driver (Bluetooth and Wi-Fi sensors or smartcard). Smartcards are RFID identification cards that contain no battery: they are passive tag and have short application range (contactless). The RFID solution can be found instead in the Livorno Port and Interporto Prato ("Il Trovatore" project); equipped portals able to identify the device on board used for the Electronic Tolling Collection are implemented in Interporto Bologna and Interporto Verona Quadrante Europa.

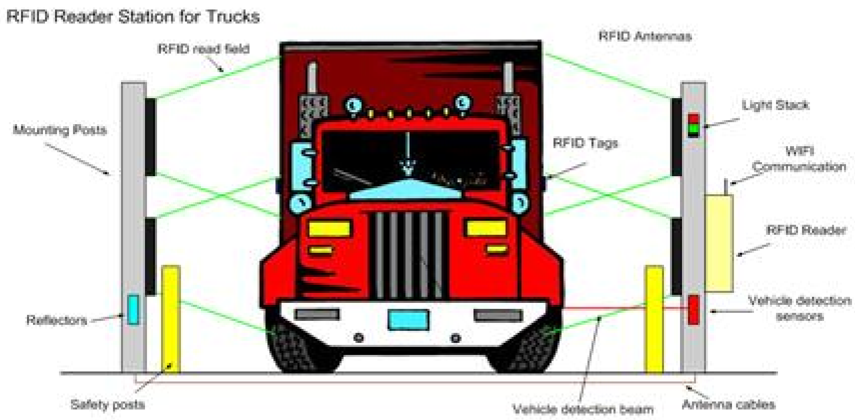


Fig. 49 Terminal gate with RFID (https://www.peacocks.com.au/solutions/business-solutions/rfid-gateway-solution)

RFID solution, as compared to OCR, has the advantage to be a cheaper technology but it requires a heavy involvement of all users/customers using the terminal since they should have the tag attached to the vehicle and or the ITU to be properly identified. Both guarantee an automatically data collection to accelerate the process for data management.

Applications are useful for two main reasons: they contribute to terminal performance improvement, affecting the indicator value, and may enable the computation of the indicators itself, as explained in some examples in Table 9. In addition, also a combination of different technologies may contribute to achieve the goals. For instance, Shi and colleagues (Shi et al., 2011) describe a possible entrance gate where the vehicle and driver information are read by a RFID tag on the truck. The information of ITU is recorded thanks to an image recognition system (OCR), both for the code and the damages detection. Finally, the driver enters a reservation number in a specific machine that automatically prints out the documents and the instructions for delivery and/or collection.

Bluetooth sensors, for example, may be used to monitor the terminal accesses, identifying and recording the device ID, it could be possible derive the time when drivers and vehicles are in selected positions and calculate the turnaround time of vehicle. In this case, the location and the quantity of each type of sensors influence their effects (see section 3.4.3). Bluetooth solution has the advantage, with respect to OCR, to guarantee the privacy of users since no data related to ITU or vehicle are detected and recorded. This feature however does not contribute to obtain any identification data automatically.

Table 9 Traceability matrix between automatic identification sensors and some performance indicators for instance (elaboration from (Carboni & Deflorio, 2018)**)**

Indicator	OCR	RFID Passive tag on ITU	RFID Active on vehicle (e.g. automatic road tolling)	Smartcard for driver	Bluetooth (and Wi-Fi) scanner
Turnaround time ITU_import	M/I	M/I			
Turnaround time ITU_export	M/I	M/I			
Physical check-in time	M/I	M/I			M
Documents exchange time	I	I	I	I	
Entrance queue	M/I		M/I		M
Entrance waiting time	M/I		M/I		M
Turnaround time	M/I		M/I		
Exit waiting time	M/I		M/I	I	M
Exit queue	M/I		M/I		M
Check-out time	M/I	M/I	M/I	I	M

M = measurement; I = improvement

3.4 The influence of ITS on the terminal process

The influence of automatic identification sensors (section 3.3) on terminal process (section 3.1) can be measured through selected performance indicators (section 3.2) using several method, as reported in Fig. 50.

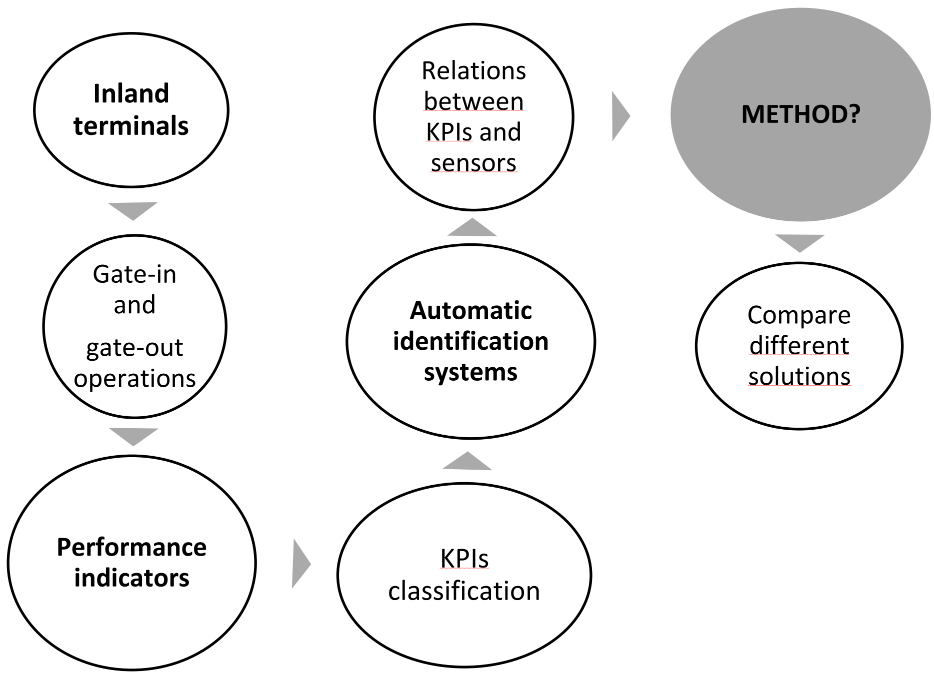


Fig. 50 Scheme for the evaluation of the influence of ITS on the terminal process

In the following sections the impact of ITS applications in a typical inland terminal will be addressed in three different ways:

- *System architecture using a standard language* (ArchiMate), the method allows a clear communication with stakeholders on the role of technologies within their business process. Both the relation between indicators and technologies, as well as the comparison of different sensors solution are modelled.
- *Terminal simulation,* the method evaluates the quality and energy performance of inland freight terminals, using a quantitative approach based on traffic microsimulation models. The model allows a comparison of chosen performance indicators in several scenarios using realistic data.
- *On-field application,* some technological solutions are tested in the field to monitor the inland terminal and evaluate the scenarios. In detail, video processing tool and Bluetooth and Wi-Fi sensors are used to support the terminal monitoring during the test period and their positive and negative features are analysed.

3.4.1 System architectures using a standard language

As mentioned in section 1.3.3, (Cimino et al., 2017) and (Caceres et al., 2015) have used BPMN approach to study terminal process. However, BPMN focus is on the process activities associated with pools, where roles and subsystems can be included (Object Management Group, 2013), whereas ArchiMate language introduces different layers, in particular those at higher levels, helpful to correlate the process with relevant requirements and justifications (strategy and motivation layers) (The Open Group, 2017).

In section 3.1 the terminal process was described through standard representation with the Business layer of ArchiMate. To evaluate and illustrate the effect of automatic identification sensors on the terminal process other two layer have been used:

- the Motivation layer to represent the stakeholders and the performance indicators;
- the Strategy layer to introduce the automation process.

The application here in only on the selected indicators particularly useful to analyse the adoption of automatic identification systems.

The motivation layer is composed by some elements:

- Stakeholder, called actors in Table 8 represented by the truck drivers and the terminal operator.
- Driver is internal or external condition that motivates stakeholder to define its goals. The terminal operator decisions can be driven by some regulations, but also by competitiveness and profit.

- Goal represents the motivation of stakeholder to achieve certain results and anything a stakeholder may desire. The goal is called scope in this thesis (e.g. improve safety, respect environment and improve terminal throughput).
- Outcome represents a result that has been achieved and is therefore considered to be a performance indicator.

Fig. 51 shows the relationship between the two main actors involved in operational process and their aims, explained through performance indicators (selected from Table 8). The performance indicators selected based on the specific purpose, namely the evaluation of the impact of automatic identification sensors, are: physical check-in time, documents exchange time, entrance queue, entrance waiting time, turnaround time, exit waiting time, exit queue, check-out time, ITU turnaround time.

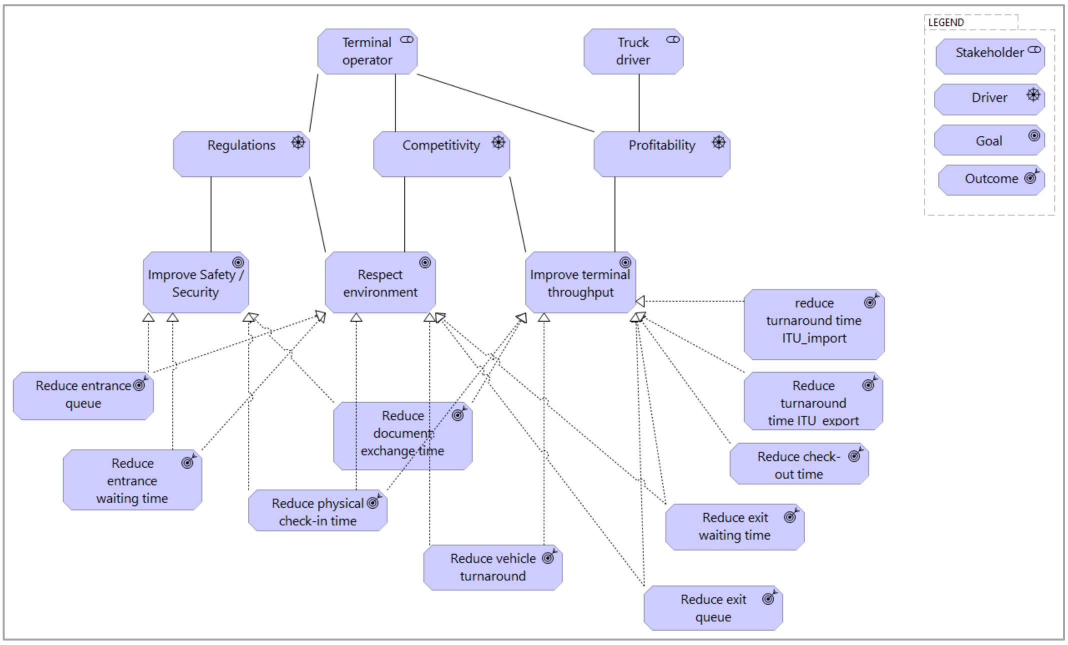


Fig. 51 Motivation layer for selected performance indicators (Carboni & Deflorio, 2018)

The strategy layer elements on the other hand are:

- Course of action, represents what an enterprise has decided to do that is the main element of the strategy, related to the outcomes. The selected performance indicators were chosen to evaluate the effects of possible automation of the check-in process, which represent the course of action in the strategy architecture.
- Capability is an ability that an active element possesses. In this case is the capability of manage the IT solution and the process.
- Resource is an asset owned or controlled by actors. These can be tangible (financial, physical...), intangible or human.

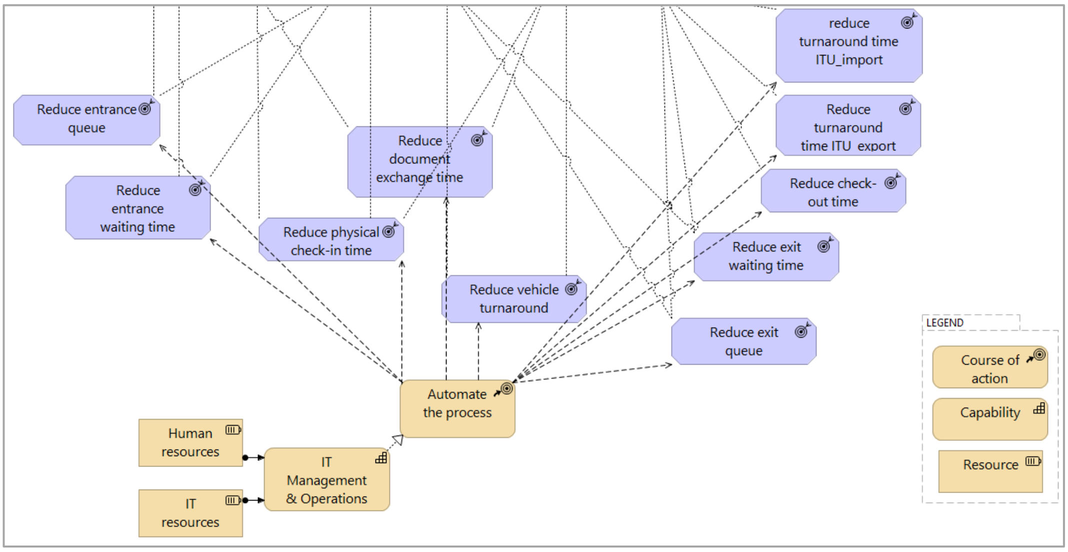


Fig. 52 Strategy and part of motivation layers (see Fig. 51) for selected performance indicators (Carboni & Deflorio, 2018)

To compare different scenarios with several sensors applications the Business layer is link with the previous one. The focus is on the check-in phase extracted from the entire terminal process (Fig. 44).

The check-in operation is a business service that starts when the truck arrives at the terminal access (initial event) and ends with the obtaining of the authorization (final event). It is composed generally by two main processes: identification and inspection. In the base scenario, we assume both processes are performed manually by the check-in operator (Fig. 53).

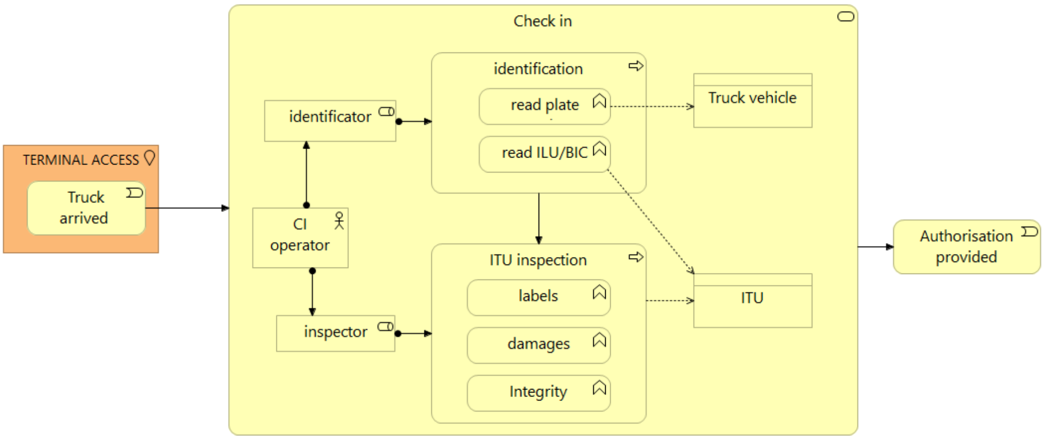
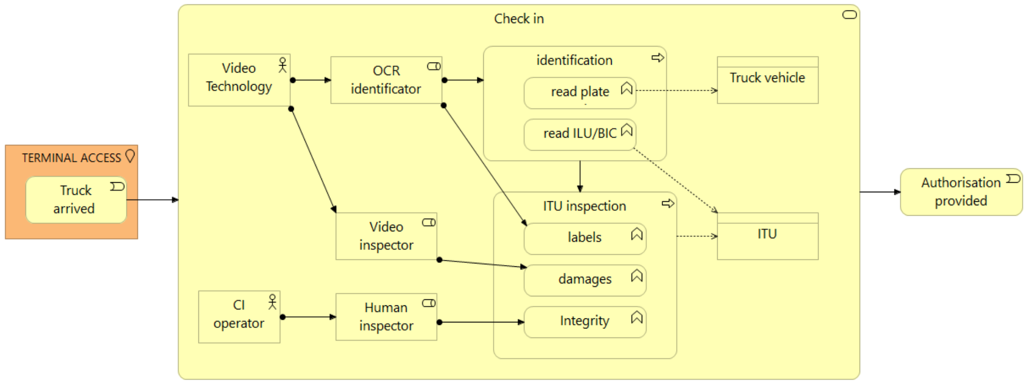
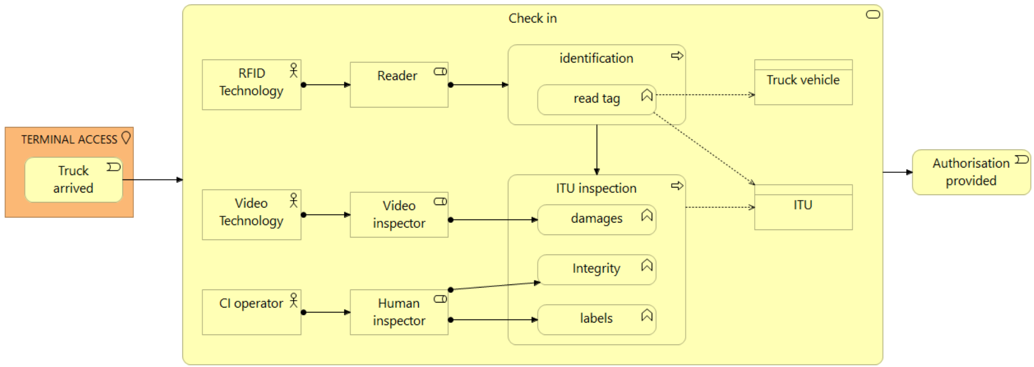


Fig. 53 Business layer: manual check-in



(a)



(b)

Fig. 54 Business layer: OCR sensors implementation (a) and RFID sensors implementation (b)

In Fig. 54 the effect of OCR and RFID implementations on check-in process for inland terminal is represented using business layer. The inclusion of OCR sensors enables the automatic identification of vehicles and ITUs through unique codes and labels. The video technology allows the collection of frames useful in case of dispute for container damage. Other scenario (RFID sensors) shows that to collect images is nevertheless necessary the video technology. The tag can be temporary or permanently associated to drivers, trucks, or ITUs. In the case of permanent tag, the information can be uniquely related to specific driver, truck or ITU thanks to a connected database. The temporary tag, on the other hand, provided at the entrance and collected at the exit of the terminal, can be useful for the tracking inside the intermodal node, but not automatically related to identification procedure (Carboni & Deflorio, 2018). The human operator remains in the process with his role of inspector to verify the ITU integrity.

Fig. 55 exposes the global architecture, in the case of OCR sensors implementation, which links the different layers (motivation, strategy and business), because the resources are associated to business actors. Thus, the architecture with the different layers aim to trace the relation between the indicators and the automatic identification technology implementation underling the role of automation. Then these representations can support the calculation of indicators by showing at which points of the process identify the events where measure them also with different scenarios. An example of measurement process is presented in the paper by Carboni & Deflorio (2018).

The approach reported in this section is similar to Cimino et al., (2017), although their focus is on the business layer for the entire harbour, whereas the aim of this thesis is on comparison between different sensors solutions and their effect on specific part of the process.

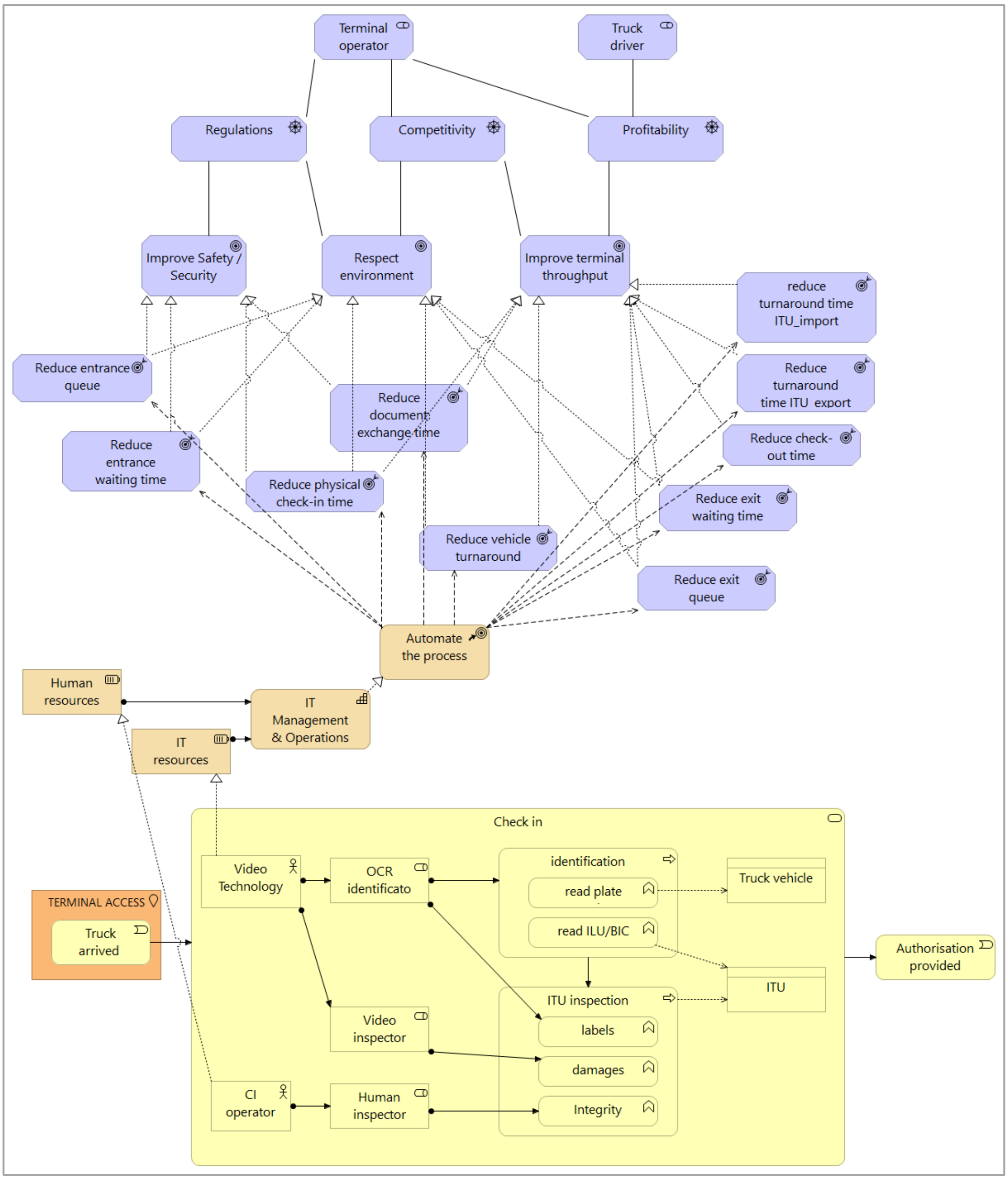


Fig. 55 Architecture of the check-in process in intermodal terminals (view of motivation, strategy and business layers)

As regards the train entrance process (Fig. 45) the effect of OCR sensors is on the identification phase as can be seen in Fig. 56. Besides, in this scenario the train composition check and the shunting can take place simultaneously. The automatic identification of ITUs and wagons id may support also the correct location of unit and this could speed up the entire process of collection, for instance.

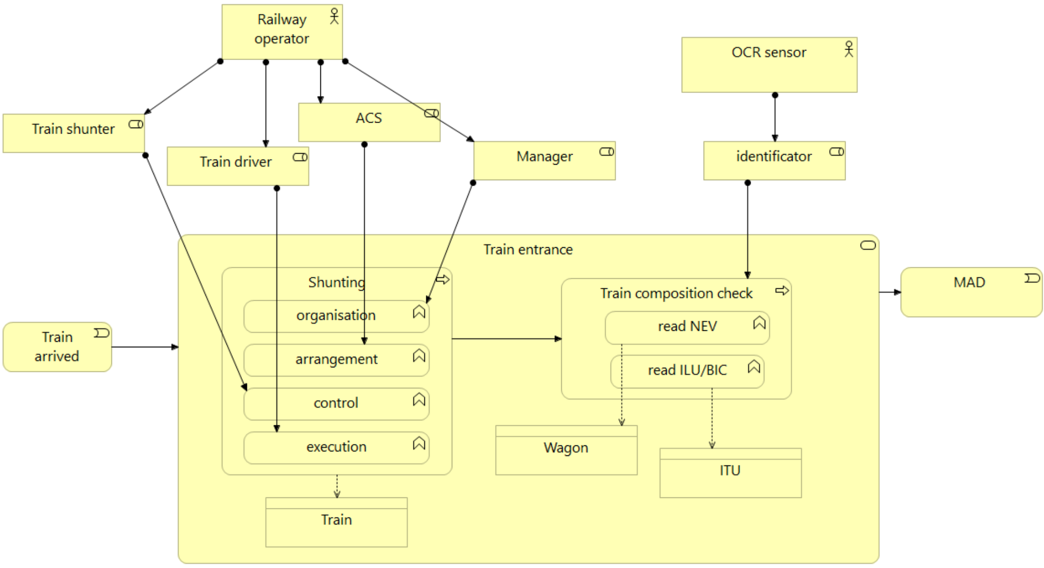


Fig. 56 Architecture of the train entrance process with OCR technology implementation (view of business layers)

3.4.2 Rail-road combined transport terminal microsimulation

The impact of ITS applications in a typical inland terminal will be addressed through a quantitative approach based on traffic microsimulation model. The method proposed allows the evaluation of quality and energy performance of inland terminal.

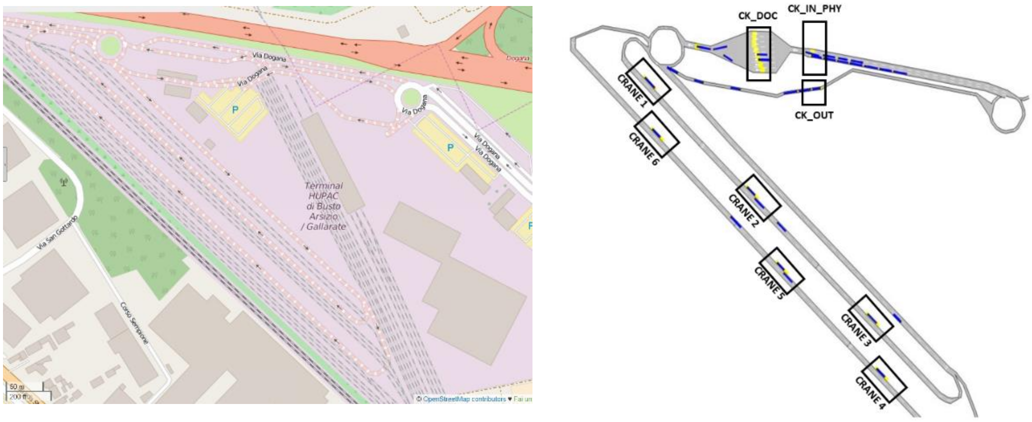
Although the relevant events of the whole process could be represented by a discrete-event simulation model, such as in Ricci et al. (2016), if the focus is on the traffic interactions along the connecting roads, vehicle queues and their energy consumptions, microsimulation tools can provide a more effective modelling. They are based on a time-sliced approach and widely used in traffic engineering studies. The terminal layout was modelled with the tool Aimsun® (Advanced Interactive Microscopic Simulator for Urban and non urban Networks) and applied to a part of large-sized Italian terminal (Hupac Busto Arsizio) based on the Open Street Map information (Fig. 57 (a)). The relevant features of the typical phases of the internal process are represented and the traffic flow data of arrivals are disaggregated by specific service needs. The methodology proposed is also presented in the previous work by Carboni & Deflorio (2017).

The typical activities under truck driver point of view, as described in previous sections (Fig. 44), are:

- physical check-in (Ck_in_phy)
- documentary checks (Ck_doc)
- loading and unloading operation with cranes or not (semi-trailer) (Crane x)
- check-out (Ck_out).

In practice, the first two operations may take place simultaneously, manually or in automatically with some technologies, such as the ones described in section

3.3, but in the initial scenario the check-in/out and documentary process occur manually in different part of the terminal layout, as shown in Fig. 57 (b).



(a) (b)

Fig. 57 (a) Terminal information from Open Street Map; (b) Positions of truck activities (trucks=blue rectangles; service stops=yellow rectangles)

In this methodology the trucks flow is simulated as public transport lines with specific stops along the route inside the inland terminal (Fig. 57 b). The stops are used to model one of the activities listed above, characterized by different times due to the usually expected operations that can take place.

In particular, eight service lines were chosen to create different hypothetical situations based on properties related to the characteristics of the client (Carboni & Deflorio, 2017):

- LINE 1–2, the vehicles should carry out the *delivery* operation. They will have to do physical check-in at the entrance and then will be served by a crane;
- LINE 3-4, these vehicles should do only the *collection*, this means that they will not have to physical check-in and they can go directly to the documents control. One crane tranships the unit and then the activity of check-out will require more time to verify the load;
- LINE 5-8, dedicated *both for collection than delivery* which are supposed to take place with two different cranes. The duration for documental control doubles to consider the two activities that required separate procedures.

The eight service lines have different paths and related durations inside the terminal due to the activity's positions. In Table 10 the hypothetical assignment of the cranes for each service lines is shown and for the lines with double service, the position for the first (I) and the second (II) operation is reported.

Table 10 Operation order* for cranes and relation with lines (Carboni & Deflorio, 2017)

Line\Crane	1	2	3	4	5	6
1			I			
2						I
3		I				
4					I	
5	II		I			
6		I			II	
7	II			I		
8				I		II

* I= first; II=second

In Table 11 some crucial data used in the microsimulation model for the base scenario are reported. In this scenario an equilibrium condition has been set for services and arrivals. It is necessary to specify that to properly calculate the frequency, the concept of "equivalent lines" is introduced. These are equal to 12: four lines with single service and four lines with double. The simplification for crane operations is important, in fact the six cranes represented as fixed stops are a strong assumption. Precisely because the electric gantry cranes on fixed tracks can cover lager areas also overrunning the action space of the nearby crane. As reported in Table 11 the time required for transhipment operations has a high deviation to consider the variability of this specific activity due to the position, type of ITU and weather conditions. The details of each line, in particular the time interval for the operations, are shown in Table 12 while some examples of their timetables are reported in Fig. 60 and Fig. 61.

All data used, including the terminal layout, although describe a realistic scenario, are assumed mainly to test the ability of the proposed approach to reproduce the required process operations and not to provide an appraisal of the terminal (Carboni & Deflorio, 2017).

The traffic simulation can be visualized by means of a graphic animation which allows to verify the correct functioning of the model and analyse the obtained effects by representing the movement of the vehicles on the network (Fig. 59). The output of the simulations containing the statistics collected during the experiments is then used to evaluate useful indicators. Any microsimulation experiment is composed by ten replications for a 1-hour simulation period and the output are evaluated on the basis of the average values (Fig. 58).

Table 11 Some important data for the simulation of the base scenario.

Data for simulation	
Crane average service time	3 minutes (±60s)
Unitary service rate (μ)	20 veh/h
Number of operative cranes	6
Total average service rate	120 veh/h
Number of service lines	8
Number of “equivalent service lines”	12
Single arrival rate (λ)	10 veh/h
Lines frequency	6 minutes (± 30s)
Documents check (one operation)	100s (± 30s)
Documents check (double operation)	200s (± 30s)
Transhipment operation	180s (± 60s)
Warm up period	30 minutes

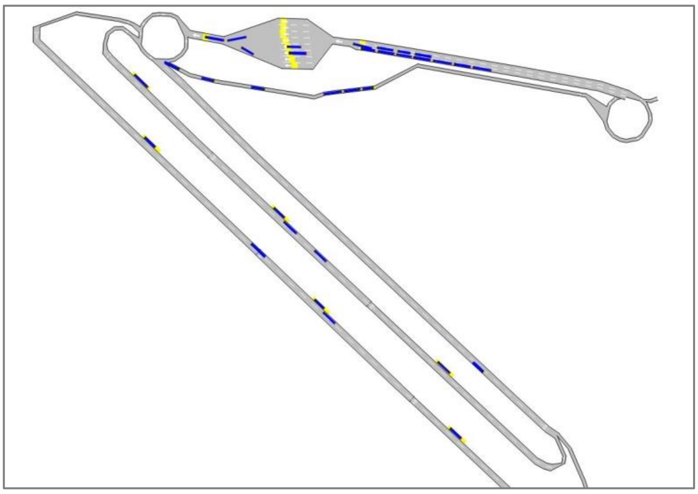


Fig. 58 Screenshot of a typical replications in Aimsun® (Carboni & Deflorio, 2017)

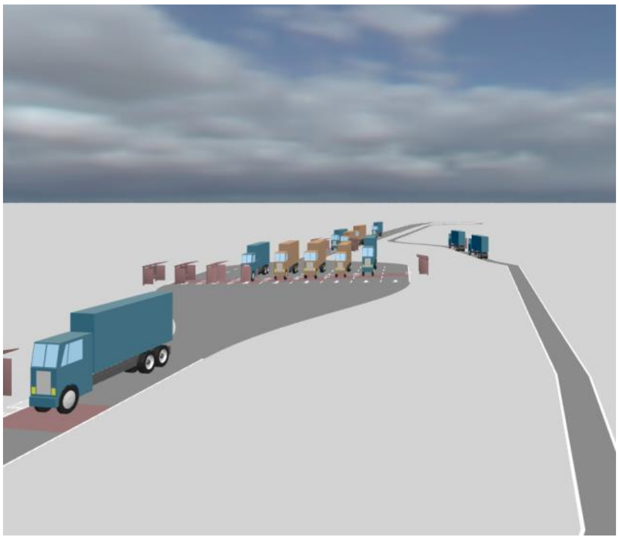


Fig. 59 3D view of simulated terminal gate in Aimsun®

Table 12 Detailed data concerning the lines of base scenario

SCENARIO 0					
Line	Operation	Stops	Time [s]	Deviation [s]	Starting time
1	Delivery	Ch_in	120	± 30	05:00:00
		Ch_doc	100	± 30	
		Barrier	20	± 5	
		Crane 3	180	± 60	
		Ch_out	20	± 5	
2	Delivery	Ch_in	120	± 30	05:00:45
		Ch_doc	100	± 30	
		Barrier	20	± 5	
		Crane 6	180	± 60	
		Ch_out	20	± 5	
3	Collection	Ch_doc	100	± 30	05:01:30
		Barrier	20	± 5	
		Crane 2	180	± 60	
		Ch_out	50	± 20	
4	Collection	Ch_doc	100	± 30	05:02:15
		Barrier	20	± 5	
		Crane 5	180	± 60	
		Ch_out	50	± 20	
5	Delivery + Collection	Ch_in	120	± 30	05:03:00
		Ch_doc	200	± 30	
		Barrier	20	± 5	
		Crane 3	180	± 60	
		Crane 1	180	± 60	
		Ch_out	50	± 20	
6	Delivery + Collection	Ch_in	120	± 30	05:03:45
		Ch_doc	200	± 30	
		Barrier	20	± 5	
		Crane 2	180	± 60	
		Crane 5	180	± 60	
		Ch_out	50	± 20	
7	Delivery + Collection	Ch_in	120	± 30	05:04:30
		Ch_doc	200	± 30	
		Barrier	20	± 5	
		Crane 4	180	± 60	
		Crane 1	180	± 60	
		Ch_out	50	± 20	
8	Delivery + Collection	Ch_in	120	± 30	05:05:15
		Ch_doc	200	± 30	
		Barrier	20	± 5	
		Crane 4	180	± 60	
		Crane 6	180	± 60	
		Ch_out	50	± 20	

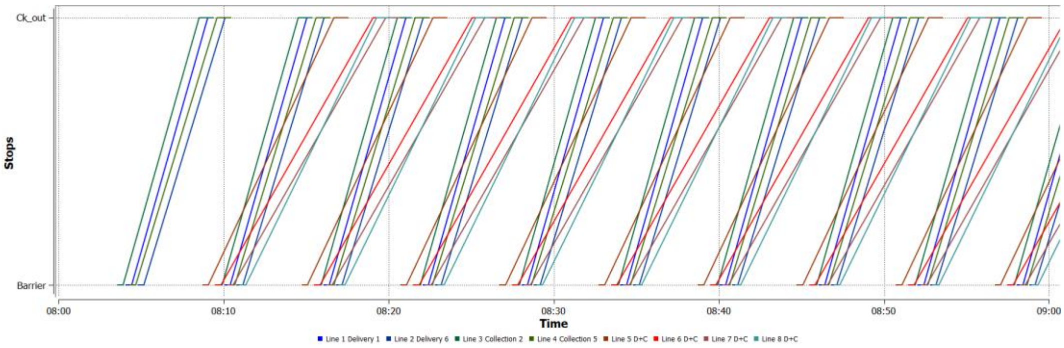
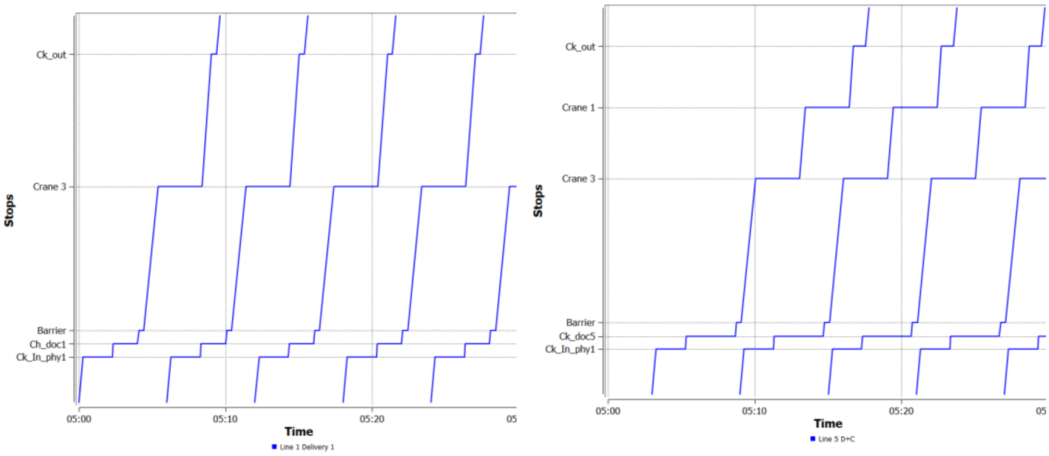


Fig. 60 Timetable for the eight service lines in the base scenario between the main stops (barrier and check-out)



(a) (b)

Fig. 61 (a) Timetable of Line 1 and (b) Line 5

The principal indicator used to evaluate the performance of rail-road terminal is the turnaround time for road vehicle, described in section 3.2, in other words the time interval between the check-in and the check-out operation (see Fig. 44). This indicator is important for several actors as shown in Table 6. In fact, for the truck driver (and the client) the turnaround time represent the time spend for terminal operations. On the other hand, the terminal operator can use this value to be more competitive. Finally, as already mentioned, less time spend in inland terminal means less time in rail-road combined transport chain, so useful to make it more competitive.

In the methodology proposed the travel time for the service lines provides a disaggregate estimation of the turnaround time. In Table 13 the main results are reported. The goodness of the method is confirmed, indeed as expected: the higher values are for the lines which perform double service and different values are observed for collection and delivery operation due to the different time for physical check-in stops.

Table 13 Base scenario: turnaround time for service line (Carboni & Deflorio, 2017)

Turnaround Time [min.]	6.15	6.30	6.45	7.00
Line 1 Delivery 1	17,0	19,7	23,0	25,2
Line 2 Delivery 6	17,4	18,7	21,7	24,4
Line 3 Collection 2	12,1	13,5	14,4	17,3
Line 4 Collection 5	12,3	14,0	14,2	16,1
Line 5 D+C	20,5	23,7	26,6	29,2
Line 6 D+C	24,8	27,3	30,0	33,0
Line 7 D+C	23,2	26,8	29,2	31,6
Line 8 D+C	23,2	26,8	28,7	32,4

The baseline scenario has been tested with two complementary scenarios, simulating respectively the decrease (7 minutes the line frequency for scenario S1) and increase (5 minutes the line frequency for S2) of the arrivals rate at terminal. The results reported in Carboni & Deflorio (2017) underline that in S1 the travel time values are quite constant, as should be in stationary conditions, on the contrary in S2 the quality performance of the terminal is affected more dramatically.

In order to observe the effect of automatic identification sensors an improved scenario is introduced (S3). In this configuration the duration of check-out operation, which is the part of the terminal where the major queue was observed during the simulation, was reduced modelling the possible effect of ITS implementation to support the operation (sensors example in section §3.3) (see Table 9 for the effect of ITS on specific indicators). The comparison between the base and the improved scenarios are reported in Table 14 to see the effect of technologies introduction on the terminal performance. Obviously, the main variation is for collection lines because directly involved in check-out phase and particularly at the end of the simulation period due to the interaction with other vehicles. Nevertheless, the effect is also on other lines since there is a unique exit gate and interaction phenomena occur.

Table 14 Turnaround time variation [%] for service line in S3 respect to base scenario (Carboni & Deflorio, 2017)

Turnaround Time [min]	6:15	6:30	6:45	7:00
Line 1 Delivery 1	-5%	-9%	-15%	-18%
Line 2 Delivery 6	-5%	-2%	-11%	-14%
Line 3 Collection 2	-10%	-8%	-18%	-25%
Line 4 Collection 5	-15%	-15%	-16%	-19%
Line 5 D+C	-3%	-8%	-7%	-11%
Line 6 D+C	-5%	-8%	-6%	-10%
Line 7 D+C	-6%	-7%	-7%	-6%
Line 8 D+C	-5%	-10%	-8%	-12%

Finally, three further scenarios are considered: one to observe the effect of automatic identification sensors during check-in operation (S4) while in S5 both the improvements are simulated (in check-in and check-out phases), the third one (S6) is set to see the effect of ITS in the worst-case scenario, so with the increase of arrival rate. In this last scenario the automatism is introduced both for check-in and check-out operations. In all cases the presence of technologies is introduced through a time reduction; in the check-in phase the deviation of time interval is high due to the possible presence of terminal operator which could intervene manually in particular cases. In this model the effect of automatic identification during the truck entrance does not affect the time required for documents control but in real case the correlation may has a bearing (see the process relations in Fig. 44).

Table 15 Turnaround time variation [%] for service line in S4 respect to base scenario

Turnaround Time [min]	6:15	6:30	6:45	7:00
Line 1 Delivery 1	-11%	-7%	-10,0%	-11%
Line 2 Delivery 6	-16%	-19%	-22%	-21%
Line 3 Collection 2	10%	13%	23%	12%
Line 4 Collection 5	22%	24%	35%	30%
Line 5 D+C	-4%	2%	0%	0%
Line 6 D+C	-9%	-7%	-5%	-7%
Line 7 D+C	-8%	-5%	-2%	-2%
Line 8 D+C	-8%	-5%	-4%	-6%

Table 16 Turnaround time variation [%] for service line in S5 respect to base scenario

Turnaround Time [min]	6:15	6:30	6:45	7:00
Line 1 Delivery 1	-24%	-30%	-34,2%	-35%
Line 2 Delivery 6	-29%	-26%	-36%	-42%
Line 3 Collection 2	5%	5%	6%	-6%
Line 4 Collection 5	3%	-7%	3%	-2%
Line 5 D+C	-7%	-14%	-15%	-20%
Line 6 D+C	-15%	-9%	-17%	-16%
Line 7 D+C	-6%	-12%	-15%	-14%
Line 8 D+C	-12%	-16%	-16%	-25%

Table 17 Turnaround time variation [%] for service line in S6 respect to S2

Turnaround Time [min]	6:15	6:30	6:45	7:00
Line 1 Delivery 1	-21%	-24%	-27,4%	-19%
Line 2 Delivery 6	-29%	-32%	-36%	-41%
Line 3 Collection 2	18%	17%	18%	13%
Line 4 Collection 5	1%	-4%	-6%	-10%
Line 5 D+C	-1%	-9%	-9%	-10%
Line 6 D+C	-15%	-17%	-14%	-15%
Line 7 D+C	-3%	-10%	-14%	-15%
Line 8 D+C	-10%	-12%	-13%	-9%

Even if the effect of technologies implementation is on all lines due to the interaction phenomena that occur, in S4, S5 and S6 the greatest impact is perceived on delivery service line because the decrease of check-in operation is relevant (Table 15, Table 16, Table 17).

To sum up, in Table 18 the main characteristics of proposed scenarios are reported. It is possible to note that the use of technologies during gate operations (in and out) could improve the performance of intermodal terminal also in the case of worst scenario (S2 vs. S6) (Fig. 62). As expected, the automation of both incoming and outgoing improves the terminal performances.

Table 18 Summary of the scenarios explored

Scenario	Rate of Arrivals	Service rate for check-out	Service rate for check-in	Average turnaround time [min]
S0	BASE	BASE	BASE	22.4
S1	-	BASE	BASE	18.7
S2	+	BASE	BASE	28.3
S3	BASE	+	BASE	20.3
S4	BASE	BASE	+	21,9
S5	BASE	+	+	18.7
S6	+	+	+	24,5

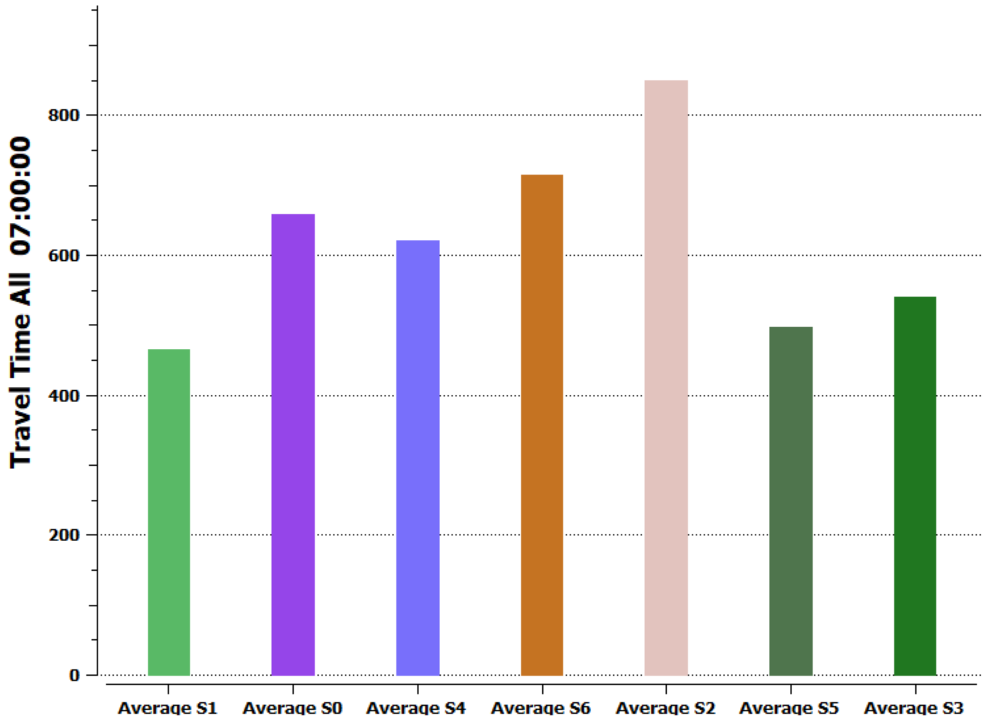


Fig. 62 Average turnaround time for the different investigated scenarios

Terminal energy evaluation

The energy analysis in inland terminal regards the aspect that has been defined above as Modal Transfer Energy (section 2.2.6).

This quantity should be considered the total energy used inside the terminal, also offices, lighting and equipment. The energy use due to the crane operations for container operation, for instance, can have an average value of 4.4 kWh/TEU

(IFEU, Öko-Institut, RMCON, & IVE, 2014). Obviously, it is a mean value because the energy consumption depends on the type of crane, ITU weight and dimension, and these data are not available, although they can be easily measured by the terminal operators. Other contribution which can be measured by the terminal operators is the energy profile of the internal road tractors.

Nevertheless, the energy consumption of truck inside the terminal can be very relevant. This quantity is another output of the terminal simulation model described in previous section (3.4.2). The indication, in this case, is the fuel consumption of trucks travelling inside the terminal from the first road section before the check-in point and the final section after the check-out point, during the simulation period.

To do this the emission model used in the methodology and also implemented in Aimsun® was propose by Panis et al. (2006). It is chosen in this study for its rich data set used to calibrate the models. The traffic emissions are modelled based on an instantaneous emission model integrated with a microscopic traffic simulation model. This model calculates vehicle emission in relation to the type, the instantaneous speed and acceleration. Panis et al. (2006) have opted to model some pollutants, for their potential health impacts and external costs: nitrogen oxides (NO_x), volatile organic compounds (VOC), car- bon dioxide (CO_2) and particulate matter (PM). In particular the CO_2 is not a real pollutant, but it is important for its effect on global climate change. The average equation to convert fuel into kg of pollutant, for CO_2 is that 1 kg of CO_2 corresponds to 0.4 l of fuel, with small different between diesel and petrol (Carboni & Deflorio, 2017).

The emission functions for each vehicle are derived with instantaneous speed and acceleration as parameters using non-linear multiple regression techniques (Panis et al., 2006):

$$E_n(t) = \max[E_{o,} f_1 + f_2 v_n(t) + f_3 v_n(t)^2 + f_4 a_n(t) + \ f_5 a_n(t)^2 + \ f_6 v_n(t) a_n(t)]$$

where $v_n(t)$and $a_n(t)$ are the instantaneous speed and acceleration of vehicle n at time t. E_0 is a lower limit of emission (g/s) specified for each vehicle and pollutant type, and f_1 to f_6 are emission constants specific for each vehicle and pollutant type determined by the regression analysis. To derive the emission functions for heavy vehicles the measurements were carried out with two types of instrumented trucks driving in real urban traffic situations: Iveco Eurocargo and Volvo FH12-420; respectively the total amount of actual measurements used are 1638 and 4514 (Panis et al., 2006).

The scenarios modelled in the traffic microsimulation tool to evaluate the energy consumption in the inland terminal by trucks and the effect of ITS implementation are the same reported in Table 18.

Table 19 Total fuel [l] for the different investigated scenarios

Total fuel used [l]	S0	S1	S2	S3	S4	S5	S6
Line 1	24,7	19,8	29,4	22,6	24,1	22,0	27,8
Line 2	25,2	21,1	30,9	23,7	24,6	22,9	29,7
Line 3	22,2	18,5	24,5	21,2	22,8	21,5	27,2
Line 4	23,1	20,0	26,1	22,6	25,4	23,4	28,5
Line 5	27,8	22,3	33,0	26,1	27,7	26,3	33,7
Line 6	36,1	30,3	41,9	34,4	36,4	34,8	42,5
Line 7	35,4	29,4	40,3	33,6	34,5	34,2	42,0
Line 8	28,3	24,5	34,6	27,1	29,2	28,1	35,4
Total	222,9	185,9	260,6	211,1	224,8	213,4	266,8
		-17%	17%	-5%	1%	-4%	20%

A disaggregate estimation of the energy used in the terminal by road vehicles has been collected during simulation for each line (Table 19). The results show that clearly the fuel consumption is consistent with the level of congestion inside the terminal. In the case of improved scenario (S3) there is a slight decrease of 5% in energy consumption. The effect of sensor implementation during the check-in phase is imperceptible probably due to the layout and the process, in fact the reduction in time procedure for entrance operation increase the total number of trucks present at the same time inside the terminal.

It is important to underline that the current estimation being related to the global process in the terminal, include also the fuel consumption during the stop phases of the vehicles, assuming the engine is on. This is not always true, although the engine is often kept on in some phases of the process, in those that require more time, it is turned off, as in the case of document control for instance.

The direct outputs of the microsimulation model are the CO_2 emissions which are strictly correlated with the chosen indicator (fuel consumption) in accordance with the Panis model. In Fig. 63 and Fig. 64 the average value of CO_2 emissions is shown aggregated for each scenario. As we expected the worst scenarios are S2 and S6, coherent with the increase of traffic flow inside the terminal; on the contrary the scenario with a decrease of traffic demand present lower level of emissions.

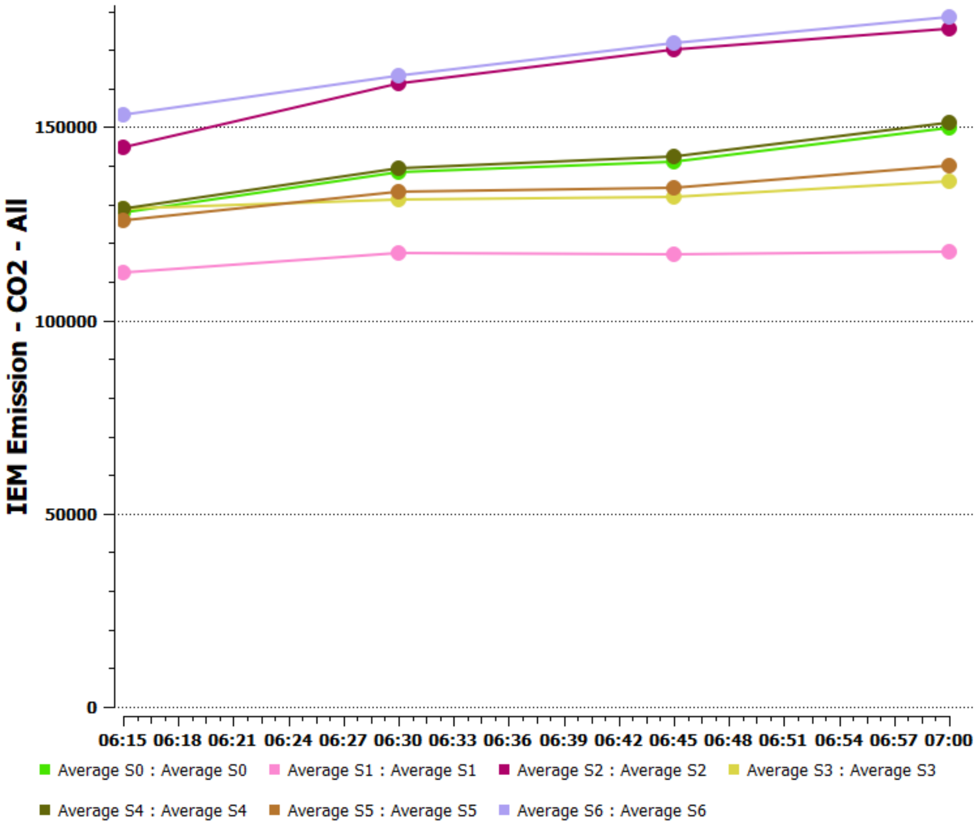


Fig. 63 Value of average CO_2 emissions estimation during the simulated period for the different investigated scenarios

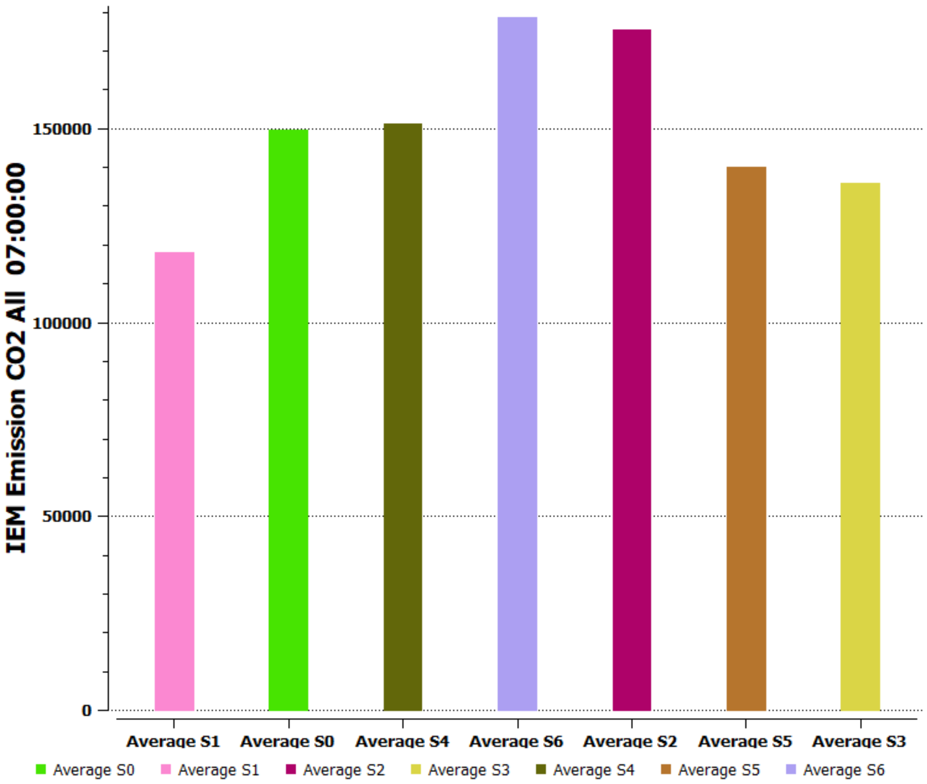


Fig. 64 Comparison of aggregated value of average CO_2 emissions estimation for the different investigated scenarios

3.4.3 On field monitoring and applications

The aim of the monitoring in field is to collect some elements useful for simulation analysis and evaluate the behaviour of different type of technologies in real scenarios. The Cluster ITS Italy 2020 Project allowed strictly collaboration with Hupac spa, as already mentioned, that enabled some test in field compatibly with the terminal daily activity. The monitoring phase described in the following sections do not aim to identify trucks or ITUs during gate operation, because these activities will be carried out by OCR systems that will be implemented after an evaluation of their benefits but represent possible approach for temporary monitoring.

Video processing

The monitoring of the terminal process took place in a typical rail-road Italian terminal thanks to the collaboration with Hupac spa within the Project ITS Italy 2020. Specifically, the focus is on the gate operations to classify the truck flow and measure some indicators, as the turnaround time. The examined area includes three main phases: check in, documents validation and check out process (Fig. 65).

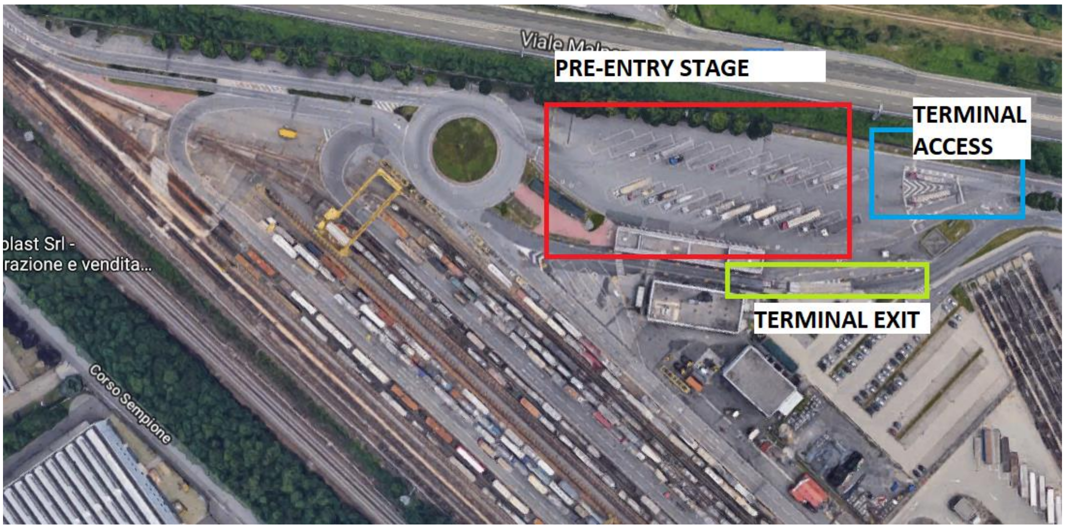


Fig. 65 Gate area of intermodal terminal Hupac in Busto Arsizio-Gallarate (VA) and operations location

The field monitoring supports the terminal simulation described in previous paragraph.

The scheme in Fig. 66 shows an example of typical trucks classification useful for the application described in this thesis and utilised also during the microsimulation (section 3.4.2). In fact, the different between the number of ITUs carry out by a truck (single or double) means different time required for documents acceptance; the same for special types of goods (as dangerous or waste) which require more documents control. In the case of check-in process, the empty trucks do not need this procedure.

The study of the framework and the scenario is the previous activity for the monitoring phase and for the simulation one.

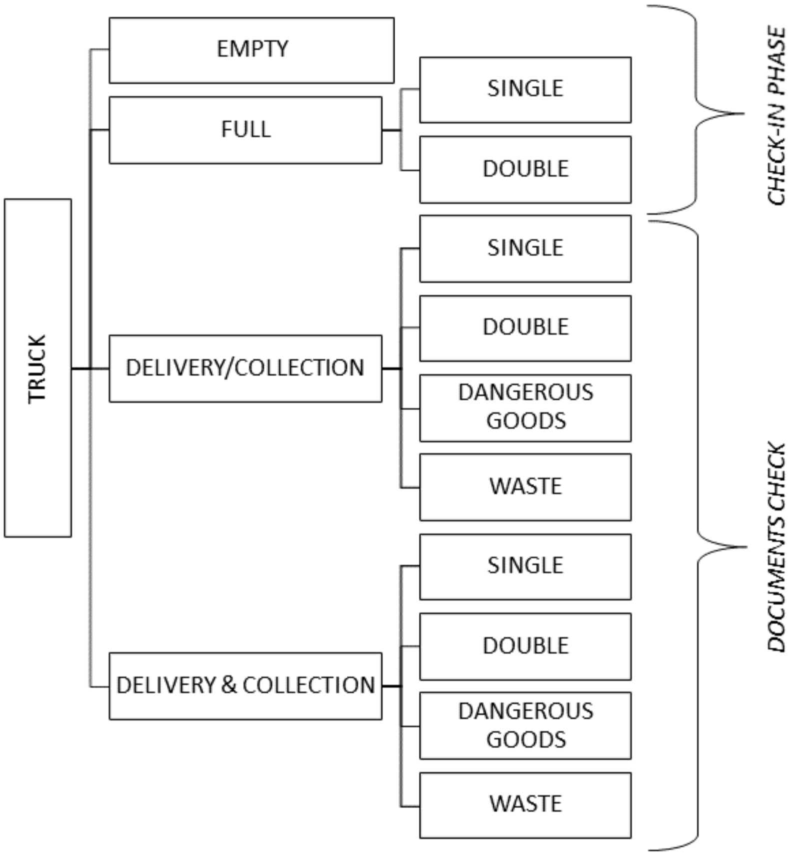


Fig. 66 Typical trucks classification

Initially, with short tests, some possible monitoring scenarios are evaluated also in relation to the applicability of the use of software for image processing. The action camera has been placed at a height of approximately 6 m in specific points which are chosen based on the terminal process and displayed in Fig. 67.

The first results have highlighted that the height is not sufficient to have a correct view for the video automatic elaboration and the supports have not provided enough stability.

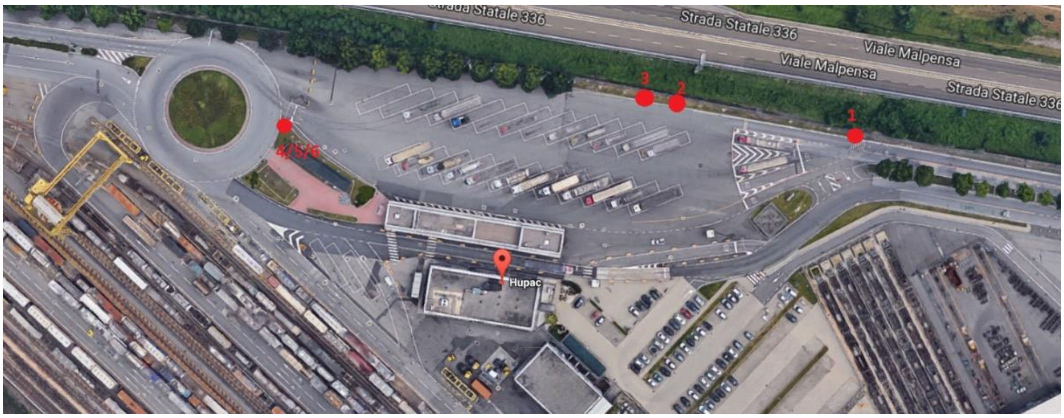


Fig. 67 Gate area of intermodal terminal Hupac and monitoring stations.

After these previous results the action camera was located on an aerial platform achieving sufficient height (10 m) and more stability. Due to the dimensions of this equipment its position is associated to the available free space, shown in Fig. 68, which allows the frame of the gate-in operations.

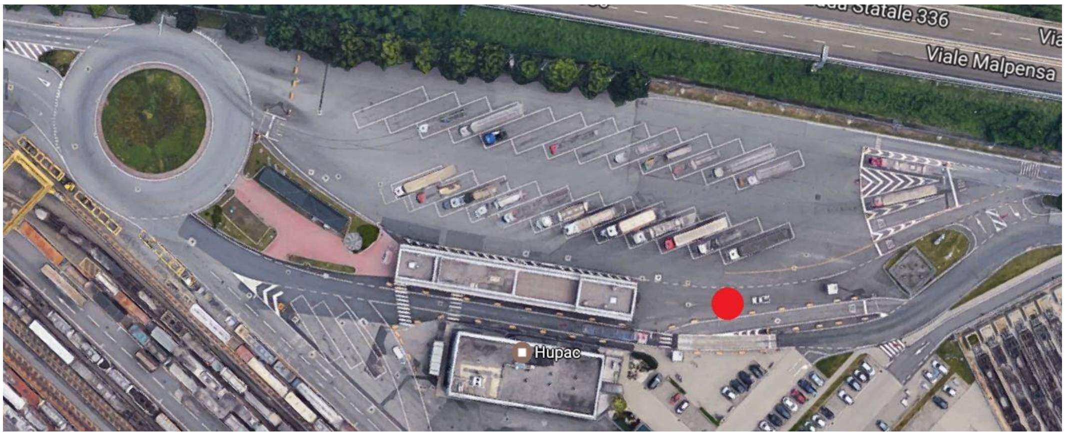


Fig. 68 Gate area of intermodal terminal Hupac and monitoring station (second phase).

The software for the video automatic elaboration to count and classify the incoming and outgoing vehicles requires a configuration of cells for the measure. In Fig. 69 the first hypothesised configuration is reported, the virtual cells layout is related to some parameters including the operations location, the type of framework. In order to verify the results goodness some cells aim to check the outputs of the others. The cells are for the counting of:

1) *check out*, for the outgoing trucks;
2) *pieni a*, for the incoming full trucks in the first lane;
3) *pieni b*, for the incoming full trucks in the second lane;
4) *vuoti*, for the incoming empty trucks (non-optimum frame)
5) *in*, for the incoming vehicle before the lane's division (start and stop phenomena)
6) *in park*, for the vehicle incoming in the parking area for documents controls, this cell verifies the measure of cell 5.
7) *check out b*, to verify the measure of cell 1.

The scenario is relatively complex to this type of automatic counting from video processing due to some aspects described below:

- the low vehicle speed means long time to cross the cell that can cause errors in the measure.
- Even if the height of the action camera has been increased, the truck size causes overlapping phenomena and the video processing software, often, detects two centres of gravity for a single vehicle for the high number of pixels (in addition to the low speed).
- The manoeuvres and the queue phenomena may cause a succession of "start and stop" that can invalidate the count.
- The trajectories of incoming vehicles are not completely predictable and therefore also the position of virtual cells for counting.

Fig. 69 Screenshot of video elaboration - first configuration (tool: *Policount*)

In Table 20 and Table 21 an example of outputs control for a video 7 minutes long is reported. The errors are due to the factors described previously which could affect the automatic measurements. The main conclusion is that this approach for on-field monitoring is not coherent with the terminal scenario because the automatic detection of vehicle incoming and outgoing from the node, in the test configuration, do not provide satisfactory results.

Table 20 Example of counting results evaluation

CELL	COUNTER	CONTROL VALUE	ERROR
1 check out	6	7	-1
2 pieni a	9	10	-1
3 pieni b	11	11	0
4 vuoti	8	5	3
5 in	43	28	15
6 in park	18	26	-8
7 check out b	5	7	-2

Table 21 Results control

TESTS								
1 check out	=	7 check out b	=	Total check-out	=	**7**		
6		5			average	6		
6 in park	=	5 in	=	Total check-in	=	**26**		
18		43			average	31		
4 vuoti	+	3 pieni b	+	2 pieni a	=	6 in park	=	**26**
8		11		9		18		28

Bluetooth and Wi-Fi sensors

The second type of technologies used to support the terminal monitoring during the test period is based on Bluetooth and Wi-Fi sensors.

Bluetooth and Wi-Fi signals are constantly being emitted by smartphones, tablets, wearable technology, and vehicular embedded systems. These signals can be identified by their device's unique Media Access Control (MAC) address. A time-synchronised scanner records the MAC address and give the direct observation of the movements of active Bluetooth devices. Bluetooth solution can be considered as temporary RFID system, since the MAC address collected is not linked to vehicles, drivers or ILU information. Due to the uniqueness of MAC address, the sensors that can detect such information can track the device over time, and consequently the individual (or vehicle in our application) who moves with that device.

To sum up, the Bluetooth technology was chosen in this case for several reasons including:

- the spread of Bluetooth and Wi-Fi technology
- lower costs
- instrumentation accessibility
- simple application
- MAC univocity
- MAC address data allows unannounced, non-participatory, and simultaneous tracking of devices (Abedi et al., 2013)
- the characteristics of anonymity of MAC address avoid potential privacy infringements
- the monitoring process does not interfere with the normal terminal activities.

Nevertheless, obviously some negative (or potentially risky) aspects must be taken into consideration, such as[13]:

- Unstable nature of the detection by the BT scanner.
- The distance between the scanners and the vehicles and the installation position (angle, height…) of the scanners could influence the recording (the capturing rate for instance).
- The vehicle speed is a significant variable during the detection.
- The scanning can be interrupted by obstacles; thus, the height of the scanner can be important.
- Environmental conditions can affect the measurement, more precisely the signal strength.

[13] (Tsubota & Yoshii, 2017) (Kitazawa et al., 2014) (Nishiuchi et al., 2015) (Abedi et al., 2013)

To begin, the proposed monitoring equipment was composed by two types of detection devices:

- *Tablet TrafficTab SMATS*, portable sensors in the following. The sensor is embedded in a tablet equipped with an external Wi-Fi antenna and operates using the Smats *TrafficTab*™ Android application (Fig. 70). The output of the program is a .csv file with the following data: MAC address of device, type of connection (0 Bluetooth Classic, 1 Bluetooth Low Energy, 2 Wi-Fi), signal strength and detection timestamps in Unix format.

Fig. 70 ***Tablet TrafficTab SMATS with Wi-Fi antenna***

- *Comark Bluelink200*, fixed sensors in the following, which are ideal for detections that require leaving the sensor at a location of interest to collect data for several hours or days. This is a detection system consisting of an IP65 case, in polycarbonate reinforced with glass fiber, with a pole-mount configuration which contains (Fig. 71):
  - CPU BT200, with the software "bt_traffic" to manage the scan and recording system.
  - Wi-Fi Transceiver.
  - Bluetooth Transceiver, able to detect Bluetooth Classic o BTLE (Bluetooth Low Energy).
  - Battery 12V, with few days of autonomy.
  - Battery charge management card, which ensures a constant power supply to the CPU and, in the event of a battery near to exhaustion, safely switches off the system.

  These semi-portable sensors can scan BT and Wi-Fi devices and record: the MAC address, the type of connection (w Wi-Fi, b Bluetooth) and the detection timestamps.

Fig. 71 ***Comark Bluelink200 sensor***

The sensors have specific detection zones, which cover a circular or directional area, depending on the type of antenna, where Bluetooth and Wi-Fi devices can be detected. The antennas available to us are of two types:

- Omnidirectional, with an angle of 360° and the range between 20 and 100 meters depending on the gain (in dB)
- Directional, with an angle between 30° and 60° and higher detection distance (100-200 m).

Table 22 Antenna technical specifications

Bluetooth Transceiver		
Bluetooth 4.0	Class 1	
Max Transfer Rate	3 Mbps	
Range frequency	2.402 ~ 2.480GHz	
Transmit output power	+19dBm (+6dBm EDR) E.I.R.P	
Receiving Sensitivity	Basic 1Mbps	-88 dBm
	EDR 2Mbps	-87 dBm
	EDR 3Mbps	-82 dBm
Working distance	Stub antenna – Stub antenna	300 m
	Dipole (3 dBi) – Dipole (3 dBi)	400 m
	Dipole (5 dBi) – Dipole (5 dBi)	600 m
	Patch antenna – Patch antenna	1 km
Temperature operating range	-20° / + 70°	
WIFI Transceiver		
TP LINK TL-WN722N		
Antenna gain	4dBi	
Standard wireless	IEE 802.11g/g/n	
Frequency	2.400-2.4835Ghz	
Transmit output power	<20dBm	
Signal rate	11-150 Mbps	
Certificates	CE, FCC, RoHS	
Temperature operating range	-10° / + 40°	

The technical specifications of the antennas used are reported in detail in Table 22.

As underlined before, the environmental conditions can affect the devices scanning capabilities, more so in the case of intermodal terminal, where the obstruction severity can be very high due to the presence of containers, which means high level of metals. In general, the physical objects (containers, offices, metal structures) and environmental factors (the terminal is an open space, so the weather conditions are relevant) contribute to the complexity of the environment (Abedi et al., 2013).

Based on the terminal area, the crucial points defined in the first hypothetic detection scenario are shown in Fig. 72. In the points A and B fixed sensors are located for continuous recording (approx. 30 hours), whereas the portable sensors are in point C and D to short scanning during the days. The proposed configuration has been guided by the purpose of covering the main movements of truck inside the terminal.

In detail, the reason for the selection of each point can be synthetize as follow:

A. Through the omnidirectional antenna the sensor can detect the incoming and outgoing trucks. The time difference between the two records is the turnaround time for the truck.
B. This way point is the unique connection between the two parts[14] of the intermodal terminal and the sensors can scan the traffic flow in both directions.
C. This point represents the entry point after check-in operation and document validation. The time difference between the same MAC record in point C and the A is the interval required for gate-in procedures. Obviously, the value can be affected by several external factors as train delay or break for truck drivers.
D. This is a validation point.

[14] The Hupac Terminal in Busto Arsizio - Gallarate is composed by two areas (connected both by road and rail.

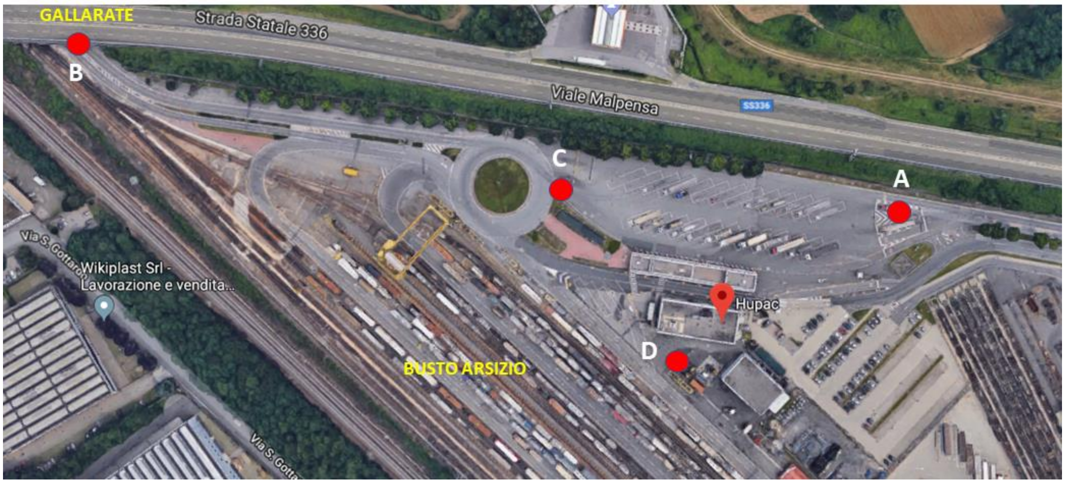


Fig. 72 Study area with sensors location (configuration 1)

To sum up, based on the possible operation that the trucks could do inside a typical intermodal terminal and their classification (Fig. 66), several possible paths which cross the crucial points may be hypothesised in such way:

- A → C → B →B → A, for delivery and/or collection on Gallarate side.
- A → C → D → A, for delivery or collection on Busto Arsizio side.
- A → C → B → B → C[15] → D → A, for truck driver who carry out two services; the first one on Gallarate side and the second one on Busto Arsizio.
- A → C → D → C[16] → B → B → A, for truck driver who carry out two services; the first one on Busto Arsizio side and the second one on Gallarate.

At the beginning, if the collected data confirm the previous hypothesized path, the base algorithm for data elaboration follow three main phases. The algorithm is developed in Python and the output of the script was also analysed using Microsoft Excel creating pivot tables to better examine the results.

1 *Data elaboration of outputs file for each monitoring point.*

The main functions of this step are reported in Fig. 73. In detail, "j" is the identification for the collection points and "i" is the MAC address. If two subsequent recordings of the same MAC address are temporal close can be grouped in a sequence. To choose when the records are to be grouped as a sequence a time value is defined ("T"). This value can be influenced by the recording timestamp for BT and Wi-Fi sensors which is peculiar for each type of instrument. First of all, the algorithm reads the file outputs from different sensors, orders data by MAC address then groups them in sequences. Finally calculate some outputs as the sequence time interval, the first time MAC was collected and the last one.

[15] This is not a real cross point, but the devices can be detected in the sensor detection zone.
[16] See footnote 11.

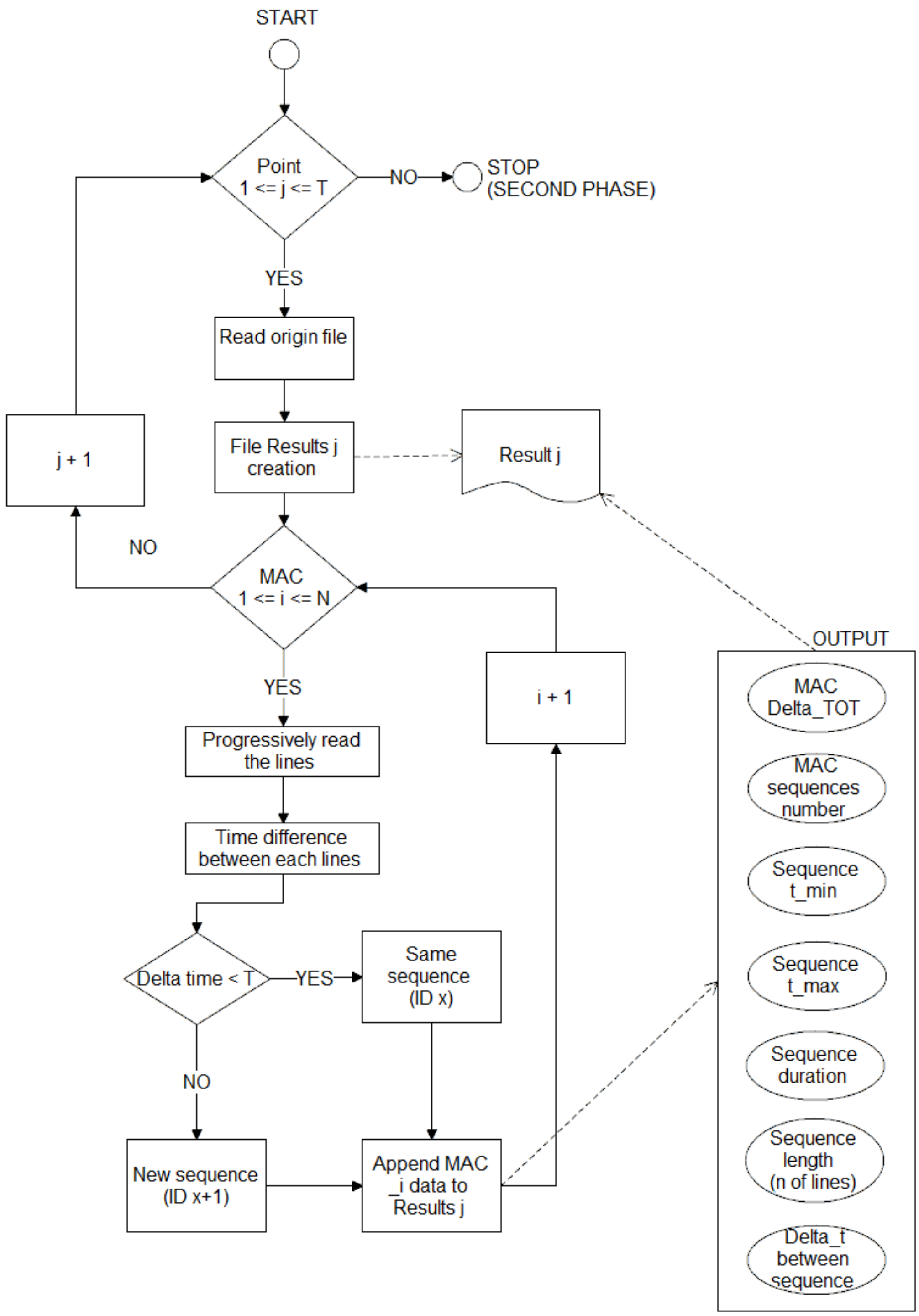


Fig. 73 Data elaboration - First step

2 *Files merging and first cleaning operations.*

The results file from each collection point are joined together and the data are aggregated by MAC address, then all the MAC addresses registered in only one point or the MAC addresses of which the time interval in specific point (j) are greater than defined value are eliminated. Abbott-Jard et al., (2013) also proposed similar filter for collected data, i.e. the application of a time limit in which the device can be detected for. This value can be defined considering for example the terminal layout, the point location, the antenna range and the type of activities which shall also be performed at that location.

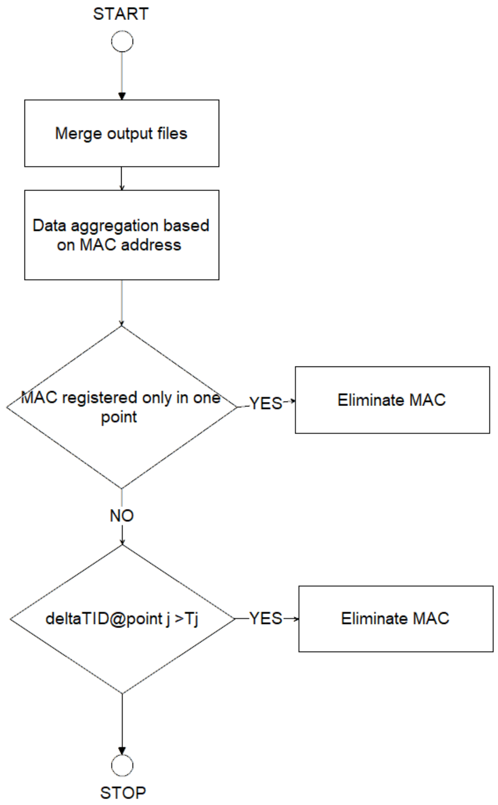


Fig. 74 Data elaboration - Second step

3 *Path identification and performance indicators calculation.*

Finally, according to the records timestamp the algorithm assign the path class to each MAC and then some indicators can be measured as the example reported in Fig. 75. This said, during path classification it is important to consider both the temporal order of activities and their time difference.

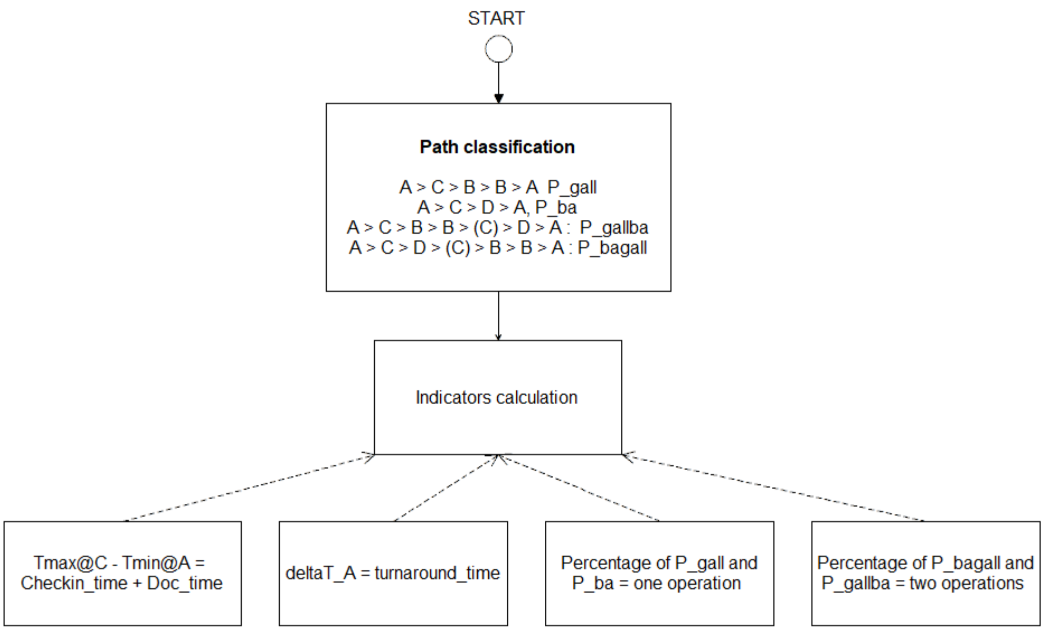


Fig. 75 Data elaboration - Third step (example)

The first data collection (Fig. 72) highlight certain particular issues, in addition to those already considered, related to our scenario, especially the main are the following:

- The two type of instruments (fixed and portable sensors) present different performances and the recording durations are not easily comparable.
- The space presents a lot of interferences such as office, terminal operators, external vehicles.
- The collection points and the activities are quite close causing high risk of overlaps in recordings.

In the end, in order to try to overcome the difficulties of the first monitoring configuration, a second configuration is proposed using only the fixed sensors and different type of antenna. As shown in Fig. 76, the focus is on the point A where are located a fixed sensor with unidirectional antenna to collect the check in and check out operations data. The fixed sensor with omnidirectional antenna was placed in point B to confirm the data collected from point A and then support the definition of criteria to select correct data.

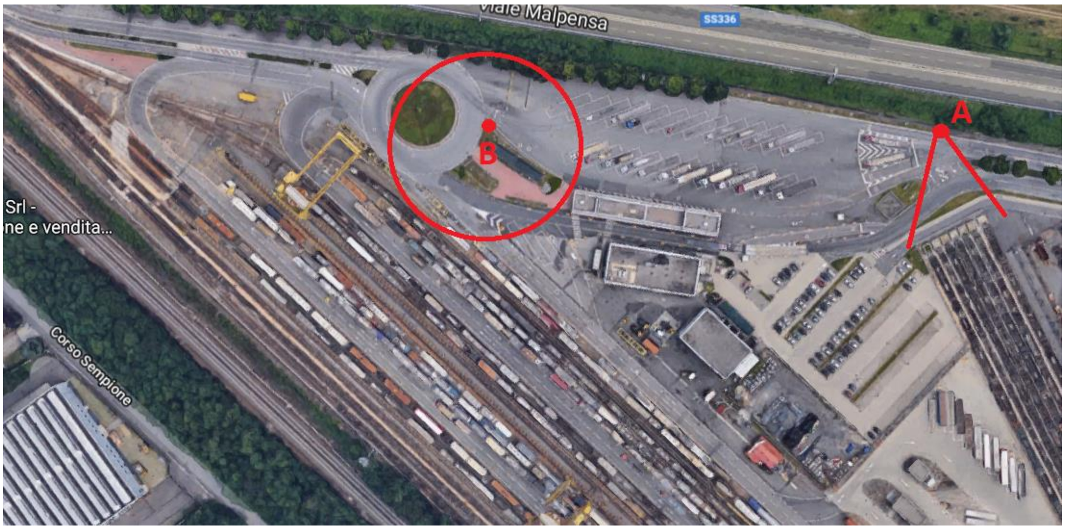


Fig. 76 Study area with sensors location (configuration 2)

Starting from the original algorithm some changes and integration have been made to adapt it to the new scenario. For instance, the functions described in first step (Fig. 73) are carried out in an already aggregated file as described in the first part of the second step (Fig. 74). Furthermore, the third phase is different because the goals in this case are different.

After an initial analysis the possible valid points present a time interval between the first time the MAC was recorded by sensor B and the first time it was recorded by sensor A inside a defined range (for example 1-20 minutes). This approach is similar to one called entrance-to-entrance in the paper by Abbott-Jard, Shah, & Bhaskar (2013). The graph in Fig. 77 show the collected data distribution and the possible outliers.

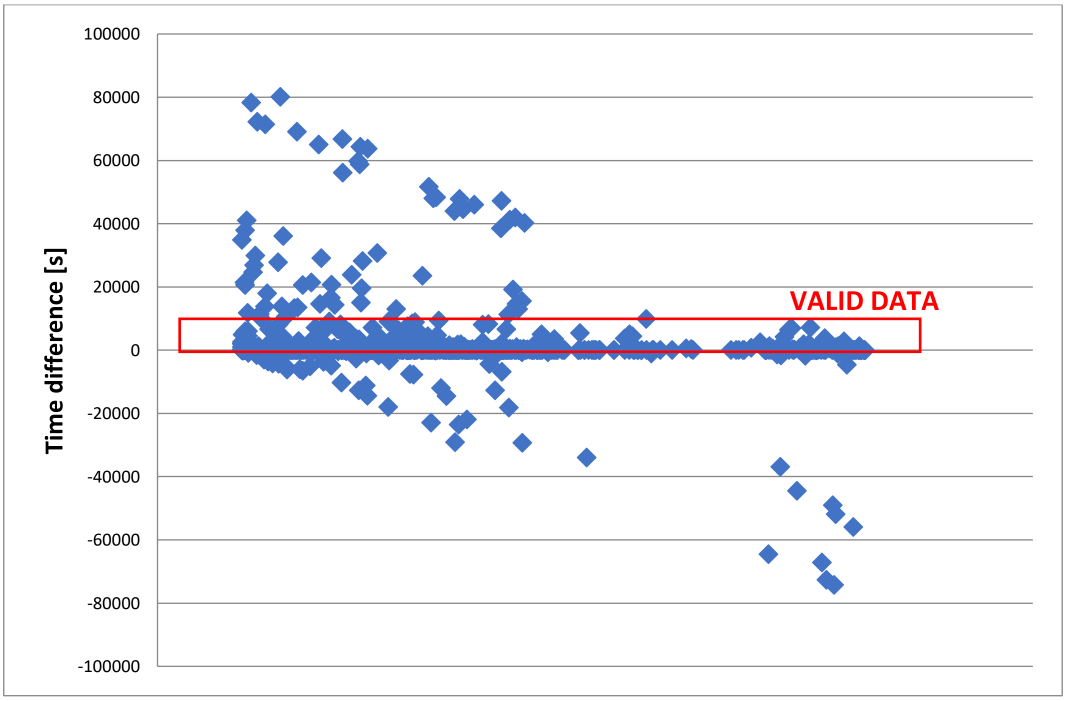


Fig. 77 Time difference between point B and A

A MAC recording is shown in Fig. 78 as an example and its main operation inside the terminal are marked. The red and blue point are respectively the *t_min* and *t_max* values for each sequence and points. During the check-in operation the device is registered by the sensor in point A, then in the course of document control the MAC was seen in both the points due to the distance between the sensors. After these operations the truck can enter inside the terminal and for a realistic time interval it was not recorded (transhipment operations). Lastly the device reappears in point B and immediately afterwards, due to the path configuration, in point A during the check-out.

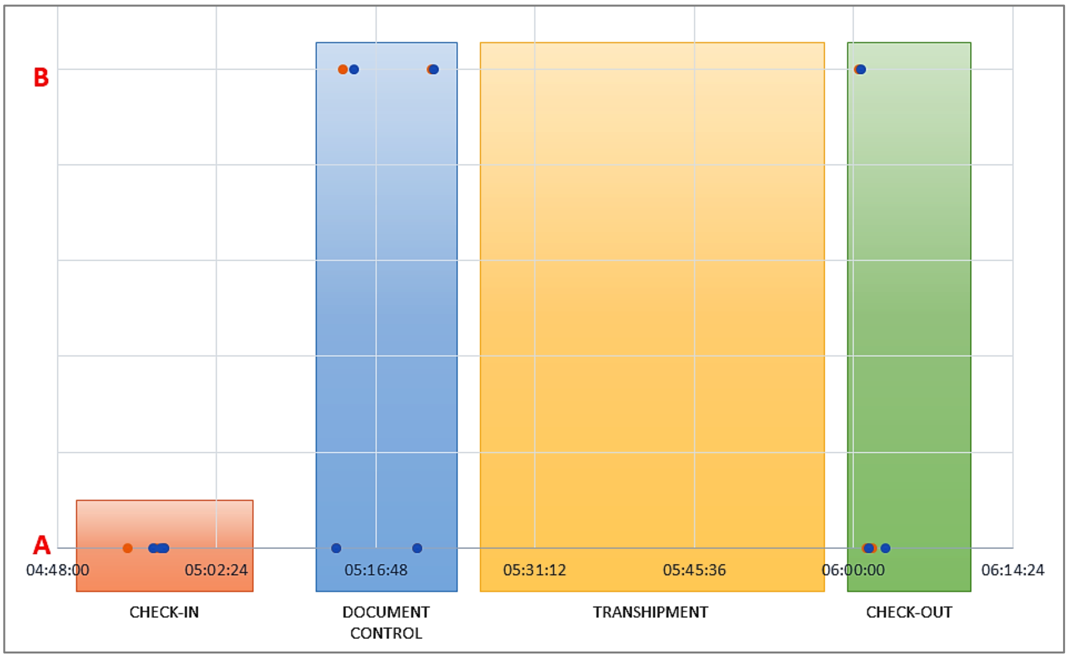


Fig. 78 Typical device recordings

It can be stated that the method proposed to monitor the terminal operations to temporary analysis is quite satisfactory. To conclude in Fig. 79 the real data of incoming trucks collected during 24 hours by terminal operator are compared with the data recorded with BT and Wi-Fi sensors during the same interval. The trends are relatively similar to the typical traffic flow inside the terminal, with the high numbers of trucks arrival during the morning and late in the afternoon (peak hour is around 4:00 pm). As one might expect, even if the trend is comparable with the real one, the total amount of truck driver detected is lower (less than 40%), but the aim of this type of technologies is not the vehicle counting but the processes identification and the calculation of the average value of some indicators.

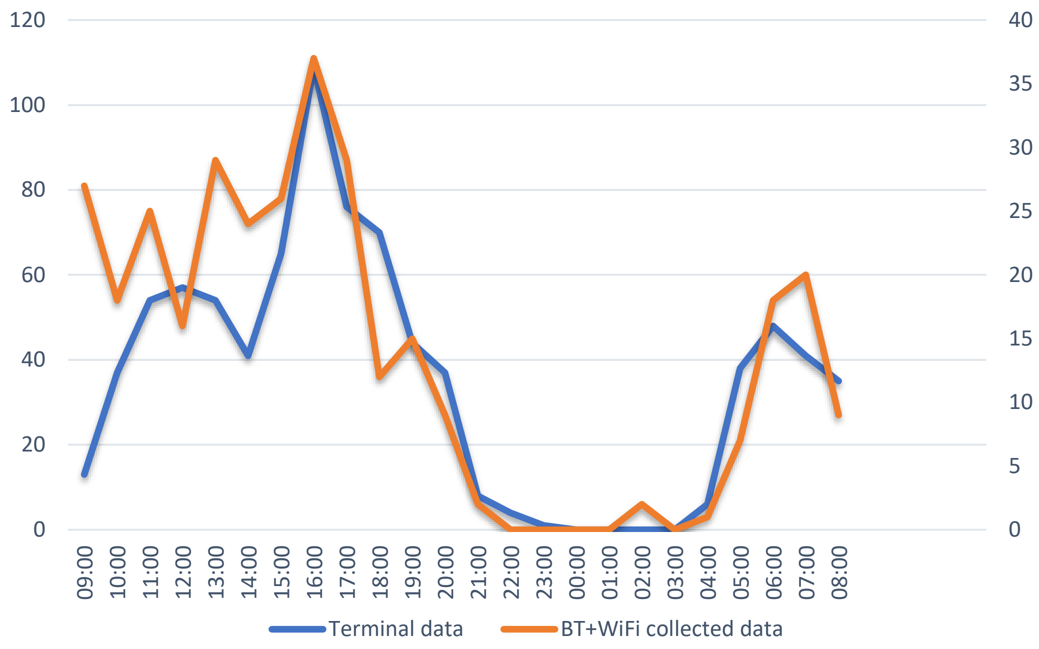


Fig. 79 Comparison between data collected by BT and Wi-Fi sensor and real data

Conclusions

Modelling the intermodal transport system is more complex than modelling the unimodal system for several reasons: each transport modes have specific characteristics, the system involved a set of actors with different roles and variety of units, vehicles and related features. The transport market is moving toward intermodal transport since the combination of several modes into an integrated continuous system can provide a good solution to achieve environmental sustainability goals required by the European Commission. One of the most important elements in the evaluation of the competitiveness of intermodal freight transport is the node, i.e. the interface between transportation modes and between several actors. In this context the thesis covered two level of detail of intermodal transport: the rail-road combined transport from origin to destination points and the rail-road terminal.

About the transport chain, the main results of the comparison between two alternatives, combined transport and road, confirms and contributes with further details to what reported in literature. In general, rail-road transport may be competitive if the external costs are internalised and if the total distances are enough to exploit the advantages of rail transport. In fact, in the case of short door-to-door distance, the terminal operations costs to transfer the unit from one transport mode to another one can limit the competitiveness of intermodal transport. To sum up, if the railway haulage is too short, the economic benefit of the intermodal alternative is overpowered by the terminal and the pre/post road haulage costs. This latter part of the transport chain covered by road must be limited not to increase the total externalities. For example, if the distance between origin and destination is around 1000 km, the total distance covered by road must be lower than 60 km so that combined transport could be convenient; this value became 100 km for a door-to-door distance around 1500 km. However, the rail-road combined transport over longer door-to-door distances (approx. 2000 km) may be cost-effective, even for a high pre/post haulage length. In this thesis the results, comparable with those in the literature but including further details, are stressed by adding technical considerations that could change them. Nowadays some technological improvements and new solutions for freight transport could influence a lot the break-even distance for combined transport convenience. In the thesis both the potential market share of the back-port connections and the positive impact on the combined transport competitiveness of alternative fuels for pre- and post-haulage with respect to traditional one have been analysed. Electric plug-in, electric (in-road charging), hydrogen fuel cell and LNG (liquefied natural gas) solutions can reduce GHG emissions, eliminate local air pollution increasing the energy efficiency, and can consequently reduce not only external but also internal costs, partially. As underlined in section 2.2.6, the electric plug-in is preferable for light urban vans or medium-duty trucks, so compatible with the pre/post- haulage for combined transport, while hydrogen fuel cell and LNG guarantee more power and autonomy also for long-haulage operations. Always on long distances, the recent "e-highway" projects and the platooning solutions should be considered. Future research could include these factors in the technical-economic analysis proposed in the second chapter, having the necessary data available. Moreover, further research could provide useful data to calibrate the discrete choice model proposed in the section 2.2.7. The estimation of model parameters was not among the aims of the thesis, but it was interesting to see how some technical considerations, reported in the second chapter, may support the definition of utility function of such model.

The rail freight transport must follow the developments of road transport in order not to lose competitiveness in its domains and far-reaching intermodal solutions more convenient for all the stakeholders. Innovations for railways should include modern vehicles such as distributed-power freight trains for controlled-temperature transport of goods and easily detectable trains monitorable along their paths. Finally, improvements of infrastructures and their equipment could allow the circulation of long and heavy trains by standardizing all European countries.

After analysing the rail-road combined transport chain and its possible improvements, the focus is on the intermodal terminal that covers a fundamental role in the competitiveness of combined transport as pointed out several times in the thesis. In fact, the total costs (including time for instance) due to terminal operations are distance-independent and they are not present in the unimodal alternative; therefore, they should have such an impact that does not unbalance the advantages of combined transport alternative.

The complexity of terminal processes is reported by referring to a typical rail-road terminal, using standard language.

Following a classification of the most common performance indicators was constructed to order the often-fragmented data available in the scientific literature. This was necessary to assess the possible impacts of the introduction of the automatic identification sensors on the terminal process. Indeed, automatic identification technologies can help to improve terminal performance not only acting on the value of the indicator, but also helping in the operation of measuring the indicator itself as resulted from the current research and field observations.

According to this, three approaches are used in this thesis to analyse the same typical intermodal terminal: a microsimulation to evaluate the impact of ITS on terminal performance, on field tests to evaluate the automatic identification sensors as a support for the measurement of performance indicators and the standard system architectures representation to build the microsimulation model and to identify the process events used as a reference for calculating the indicators. The output of the methodology proposed in this thesis is the use of different approaches to analyse the problem from different but interrelated perspectives.

In detail, the system architectures of terminal process, using standard language, and in particular those of the gate operations support the calculations of defined performance indicators and their relationship with actors and scope, through the *Motivation* and *Strategy* layer of ArchiMate language. Then, the *Business* layer allows a clear communication with stakeholders, showing the main events of the process where measure the performance indicators also with different scenarios which can include also sensors implementations for units and vehicles automatic identifications.

The second approach proposed in this thesis to analyse the impact of ITS applications in a typical inland terminal is a quantitative approach based on traffic microsimulation model. The proposed method allows the evaluation of quality and energy performance of inland terminal in several scenarios using realistic data and the description of operative process and phases represented in the standard system architectures representation. The scenarios have been prepared varying the arrival rate, the time procedure for check-in and check-out operations, to take into account the automatic identification sensors implementations. Results show that the fuel consumption is consistent with the level of congestion inside the terminal and that the use of technologies could improve the performance of intermodal terminal also in the case of worst scenario (increased traffic flow). The ITS implementation leads to a reduction of about 16% of the turnaround time in the case of base traffic demand and of about 13% in the scenario of increased traffic flow. The model can be used as a decision support tool for terminal operators to provide an overview of the current state of the system, to explore strategies in a critical scenario and to define possible improvements.

Finally, a real application in the field of technological system is presented. The monitoring phase aims to collects some elements useful for simulation analysis and to evaluate the behaviour of different types of technologies in real scenarios. The Cluster ITS Italy 2020 Project provided strictly collaboration with an important terminal operator that enabled some test in field, compatibly with the terminal daily activity. The described monitoring phase does not aim to identify trucks or ITUs during gate operation, since these activities will be carried out by OCR systems that will be implemented after an evaluation of their benefits, but to represent possible approach for temporary monitoring. In the first phase, the tests were carried out with the video technologies and then with Bluetooth and Wi-Fi sensors. The first equipment has highlighted some issues but has allowed an excellent observation for the definition of the following scenarios. Then, after investigating different monitoring scenario, the final trends obtained from data collected with BT sensors are relatively similar to those of a scenario with typical traffic flows inside the terminal, even if the sampling rate is lower than 40%. Further tests, also in other intermodal terminals, can improve the data elaboration algorithm in order to calculate average performance indicators.

To conclude the use of ITS could improve the performance of intermodal terminal in terms of quality and energy efficiency, which could also generates economic benefits and more competitiveness for the combined transport. Moreover, the technologies allow better monitoring of the terminal itself and its operations.

List of publications

The research activities presented in this PhD thesis led to the following scientific publications:

- Carboni A., Deflorio F. (2018), *Performance indicators and automatic identification systems in inland freight terminals for intermodal transport*, in IET Intelligent Transport Systems, Volume 12, Issue 4, May 2018, p. 309–318, doi 10.1049/iet-ts.2017.0349. (Scopus)
- Carboni A., Dalla Chiara B. (2018), *Range of technical-economic competitiveness of the rail-road combined transport* in European Transport Research Review, Volume 10, Issue 2, September 2018, doi: 10.1186/s12544-018-0319-3. (Scopus).
- Dalla Chiara B., Deflorio F., Carboni A. (2017), *The basic technologies for ITS and their applications: the present and future of traffic and vehicle monitoring*, In Nova Science Publishers (Ed.), Intelligent Transport Systems (ITS): Past, Present and Future Directions, p. 7-58. (Scopus)
- Carboni A., Deflorio F. (2017), *Quality and energy evaluation of rail-road terminals by microsimulation*, Transport Infrastructure and Systems: Proceedings of the AIIT International Congress on Transport Infrastructure and Systems (Rome, Italy, 10-12 April 2017), Editors G. Dell'Acqua and F. Wegman, CRC Press, ISBN 9781138030091. (Scopus)
- Pirra M., Carboni A., Deflorio F. (2018), *Monitoring urban accessibility for freight delivery services from vehicles traces and network modelling*, poster session at International Scientific Conference on Mobility and Transport Urban Mobility – mobil.TUM 2018, 13-14 June 2018, Munich, Germany.

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